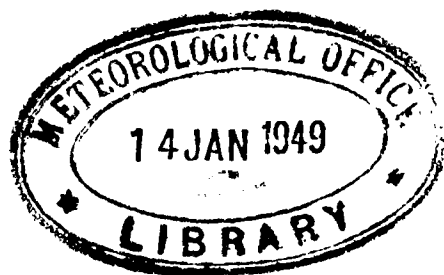


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Frontispiece]



DR. C. E. P. BROOKS, I.S.O.

Photograph by M. Martin.

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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DR. C. E. P. BROOKS, I.S.O.

It is granted to few of us to devote over 40 years of our careers to the study of a particular branch of meteorology. Dr. Brooks was, however, given this opportunity, and everybody knows the excellent use that he has made of it.

Brooks entered the Meteorological Office as a Probationer on October 4, 1907. The following month he was posted to the Library Branch of the Statistical Division. The Statistical Division of that time was the forerunner of what we now call the Climatology Division, and it is with the Library and Climatology Division that Brooks has remained uninterruptedly associated until his retirement this month.

Five years after joining the Meteorological Office, Brooks graduated as an external student of London University with Honours in Geology. This was followed by the M.Sc. in 1916 and the D.Sc. in 1926. The acquisition of these academic honours affords a striking illustration of what can be achieved by ability and hard work.

Brooks has published a very large number of papers on climatology. His studies have not been confined to the climate of the British Isles, but have embraced the whole world. He has, for example, made a special study of the world distribution of thunderstorms. Another field in which he has left his mark is in the study of changes of climate over the world in geological time. Brooks was always an omnivorous reader, and he possessed to a remarkable degree the ability to remember a vast amount of what he read. His reputation as a climatologist is world-wide, and his advice has been sought by meteorologists in many countries. His name will always be associated with the production of the first 25 years of the *Réseau Mondial*, that great conception of Sir Napier Shaw's which fell to Dr. Brooks to implement.

Mention was made earlier of Brooks' association with the Meteorological Office Library. The Meteorological Office owes a great debt to Dr. Brooks for having built up the present excellent Library. When he joined it, the Library was a relatively small affair; Brooks has grown up with it, leaving his mark firmly impressed upon it. Working in close association with the Librarian of the Royal Meteorological Society, Brooks has made it possible for meteorologists in this country to have access to almost every meteorological paper they are likely to call for. He has also been primarily responsible for the introduction into British meteorology of the Universal Decimal Classification System of Notation.

Brooks' fluent literary style made him the obvious choice for Editor of the *Meteorological Magazine*, a post which he has filled with distinction for 22 years. The zeal with which he performed this task is illustrated by the fact that, although the *Meteorological Magazine* could not be printed during the war, a typescript edition was prepared at Stonehouse and circulated among Headquarters.

From his early days, Brooks has shown a great interest in statistical climatology, and he has been largely responsible for the recent developments which have taken place in this field. He is at the moment engaged in writing an official manual on the subject, which promises to become of increasing importance.

Brooks has represented the Meteorological Office at many international meetings, and last year was the Meteorological Office member on the I.M.O. Commissions for Climatology and Bibliography and Publications at Toronto.

The contribution which Dr. Brooks has made to the work of the Meteorological Office was recognised by his creation as a Companion of the Imperial Service Order in June of this year. Rarely can this distinction have been so richly deserved.

On the human side we shall think of Brooks as a colleague who was always anxious to help and who never spared himself in the common cause. His sincerity and good humour gained him the friendship of all who had dealings with him.

Dr. Brooks retired on November 10 from his permanent appointment in the Meteorological Office, but I am glad to say that he has agreed to accept a part-time appointment which will enable him to continue to help us. Although he is not leaving us for good, it has been thought that the present occasion is a suitable opportunity for expressing our appreciation of all that he has done for us, and for wishing him many years of health and happiness yet to come.

Presentation to Dr. C. E. P. Brooks

The presentation of a comptometer and a clock to Dr. Brooks on his retirement was made by the Director on behalf of the staff of the Office before the Discussion on November 29.

Expressing the good wishes of the staff to Dr. Brooks the Director gave the appreciation of Dr. Brooks' career which is printed above.

Dr. Brooks, thanking the staff for the gift, said that perhaps in future they would think of him as racing the comptometer against the clock. With the first money he had earned with his pen forty years ago he had bought as a memento a clock which strangely broke down almost on the day of his semi-retirement. This new one would be a permanent memento of the kindness of the Office. As for the comptometer he always had some correlation coefficients to work out or other calculations on hand. Referring to his career he mentioned that he had originally intended to be a geologist and had become a meteorologist rather by accident. He did not regret this as geology was rather a lonely profession and he had never been lonely in the Meteorological Office, the staff of which were always so friendly. He had thoroughly enjoyed his forty-one years full-time work in the Office but was enjoying his semi-retirement even more.

TWEED VALLEY FLOODS

Heavy rainfall of August 11–12, 1948

By J. GLASSPOOLE, Ph.D.

The unprecedented floods in the border country, resulting from the heavy rains of August 11–12, caused widespread damage, estimated as likely to exceed £1,000,000 in value in Berwickshire alone. The map on p. 4 shows the distribution of the rainfall for August 12. The largest values for the 12th occurred along the main valley of the River Tweed, where a large area received more than 5 in., but there was also rather more than 5 in. over part of the Lammermuir Hills, at the headwaters of the Whiteadder, which flows into the Tweed a few miles above Berwick-on-Tweed. The daily amounts for the 12th at the four stations in the Tweed Valley, as set out below, correspond to from 20–23 per cent. of the average annual rainfall, and at Kingside in Lammermuir to 16 per cent. So large a proportion of the average annual amount rarely falls on one day in this country. The proportion was greater, being from 25–30 per cent., near Norwich on August 26, 1912, at Doncaster on September 17, 1913, at Bruton on June 28, 1917, and at Cannington on August 18, 1924.

The proportion was also probably exceeded by the rains which caused the Moray floods of August 1829 but no records are available for the area of heaviest rain.

The amounts for August 12, 1948, are the largest on record for this area, the previous largest for one day for Berwickshire being 3·30 in. on June 24, 1911.

Rainfall, August 6–12.—The daily values for the seven days August 6–12 are set out below for four stations situated from Kelso down the main valley to Tweedhill, as well as for Kingside in Lammermuir.

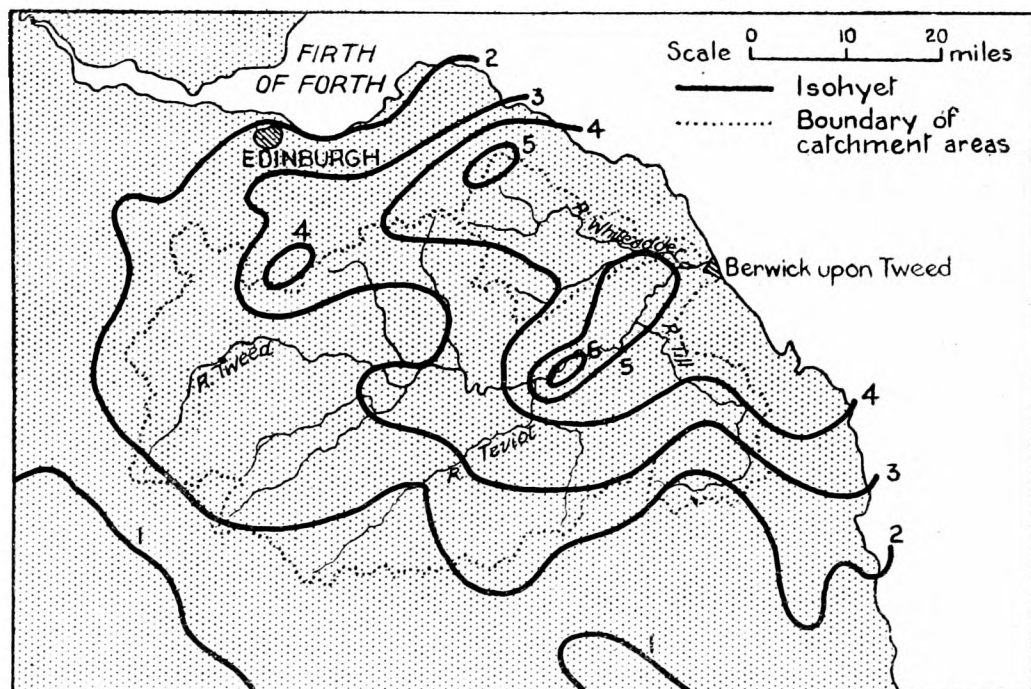
	Daily rainfall in early August							Total
	6th	7th	8th	9th	10th	11th	12th	
	<i>inches</i>							
Kelso (Floors Castle) ..	0·16	1·09	0·20	0·15	0·02	0·54	6·21	8·37
Hendersyde Park ..	0·18	1·10	0·19	0·10	0·01	0·70	5·42	7·70
Swinton House ..	0·23	1·37	0·26	0·11	0·08	0·88	5·10	8·03
Tweedhill (Hutton Parish)	0·32	1·93	0·42	0·22	0·00	0·73	5·55	9·17
Kingside in Lammermuir	0·50	2·64	1·44	0·04	0·05	0·47	5·48	10·62

A measurement for the 12th was also made, using a standard gauge, at Carham Hall, Cornhill-on-Tweed, Northumberland, some 7 miles east of Floors Castle, of 6·25 in., but the daily amounts for the other days are not available. The totals for August 6–12 correspond to from 30–35 per cent. of the average annual rainfall amounts at these stations, and so large a proportion of the annual average in 7 days is a rare occurrence anywhere in this country.

Duration and intensity of the heavy rain.—The incidence of the rainfall of the Upper Till, draining to the Tweed below Coldstream, is probably represented by the record at Howick Hall, to the east of Alnwick, where the amounts for the 11th and 12th were 1·21 and 3·22 in. Of this total of 4·43 in. as much as 4·34 in. fell in 24 hours from 10 p.m. on the 11th to 10 p.m. on the 12th. The heaviest rain occurred there between 9 a.m. and 2 p.m., when in 5 hours 2·59 in. was recorded at a rate of about $\frac{1}{2}$ in. per hour. At Swinton House, towards Duns on the other side of the River Tweed, where the amounts for the 11th and 12th were 0·88 and 5·10 in., the heaviest rain was later, 1·90 in. falling in 2 hours after 4.40 p.m. and the total of 5·10 in. being confined mainly to 15 hours from 9 a.m. to midnight.

Area covered by the heavy rain.—For August 12, 1948, the areas, in square miles, covered by falls exceeding specified amounts (not restricted to the Tweed Valley) are set out below compared with the corresponding values for the Bruton storm of June 28, 1917, and Norwich rainfall of August 26, 1912*

	Tweed	Bruton <i>square miles</i>	Norwich
more than 6 in.	8	85	268
more than 5 in.	130	288	720
more than 4 in.	800	809	1,071
more than 3 in.	1,525	1,931	2,007
more than 2 in.	2,900	4,419	3,827



RAINFALL MAP OF AUGUST 12, 1948 (Isohyets are in inches)

So far as the area with more than 4 in. is concerned the recent Tweed-Valley rains are therefore comparable with those of Bruton and Norwich. In the case of the Bruton storm it is considered that this rain fell in 16 hours, while in the Norwich floods, as much as 550 sq. miles received more than 6 in. and 1,660 sq. miles more than 4 in., in 20 hours on August 26–27, 1912.

Volume of rain-water in the Tweed Valley.—The general rainfall of this period is set out below both for (a) the whole of the Tweed Valley and (b) for the Tweed Valley excluding the Whiteadder, which enters the Tweed a few miles above the estuary.

	(a)	(b)
	in.	in.
August 11	0·6	0·5
August 12	3·2	3·1
August 6–12 (7 days)	5·4	5·1

*GLASSPOOLE, J.; The areas covered by intense and widespread falls of rain. *Proc. Inst. Civil Engrs., London*, 229, 1930, p. 137.

Adopting the areas for the Tweed and Tweed less Whiteadder, used in *British Rainfall*, of 1,904 and 1,705 sq. miles respectively, the general rainfall values for August 12 correspond to volumes of (a) almost 400 million tons, and (b) almost 340 million tons (the difference 60 million tons representing the amount falling on the Whiteadder area).

Flooding in the Tweed Valley.—Following the heavy rain in the Tweed Valley on the 7th the Press on the 9th reported that the local swimming-club races had to be cancelled at Berwick-on-Tweed owing to the river being in spate. The 10th and 11th were poor drying days so that the ground remained saturated. From the early hours of the 12th there was continuous rain, by 3 p.m. the hillside streams had become minor torrents and by 6 p.m. the Tweed tributaries had overflowed their banks in the upper reaches. The worst flooding in the lower Tweed is reported to have taken place between 10 p.m. on the 12th and 11 a.m. on the 13th, with the maximum flood about 3 a.m. on the 13th. The peak is reported to have reached the mouth of the Tweed between 3 a.m. and 6 a.m. on the 13th, roughly 12 hours after floods had occurred in the upper reaches.

Synoptic situation

BY C. K. M. DOUGLAS, B.A.

The synoptic situation associated with the abnormal rainfall of August 12 is shown on the accompanying charts. At 0600 there was a shallow depression

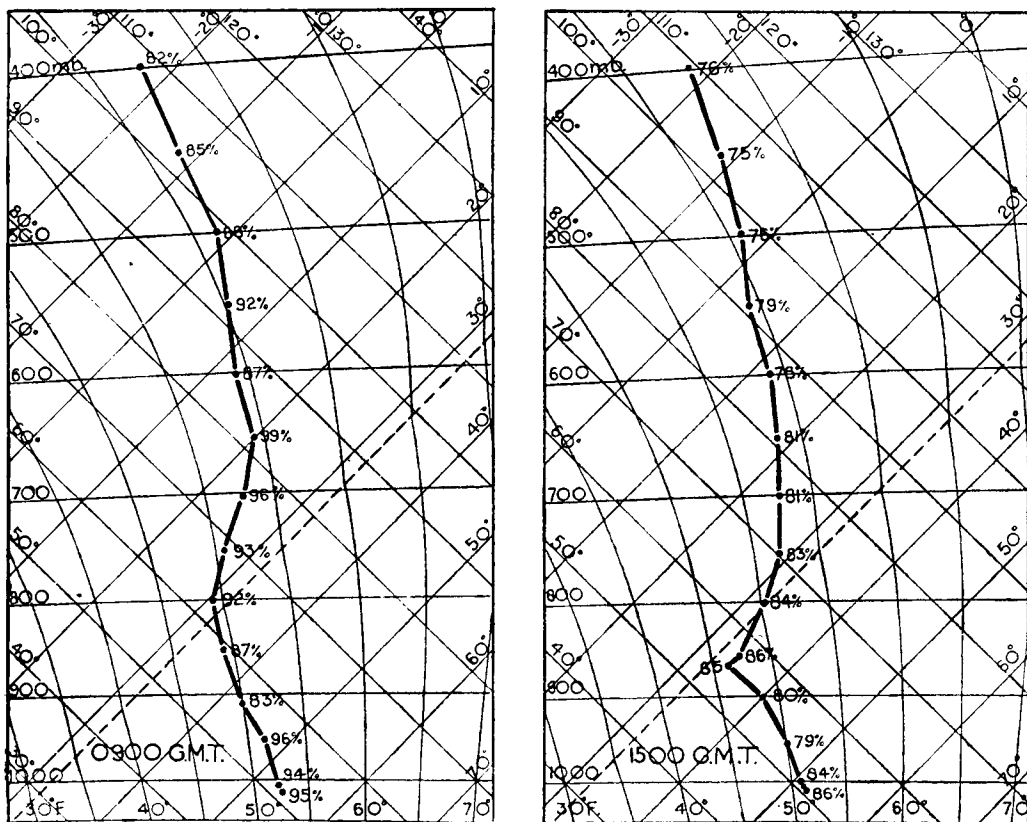


FIG. 1—TEPHIGRAMS FOR LEUCHARS ON AUGUST 12
Relative humidities are included

centred off the Norfolk coast. Its previous track is shown by the broken line joining the crosses which marks its position at successive 6-hourly intervals. It had moved east-south-east to a position off Valentia, then east, and finally east-north-east across Wales and England. Its comparatively slow motion had allowed its occlusion to become spiralled, and in addition the marked development of the upper trough behind it, due to the extraneous influence described below, produced a movement of the occlusion and a bulging of the depression towards north-east England and Scotland. The part of the spiralled occlusion nearest to the centre was no longer traceable, since there was no discontinuity at sea level and the rainfall had become patchy and mainly slight in that area. That part of the occlusion affecting our northern districts was of

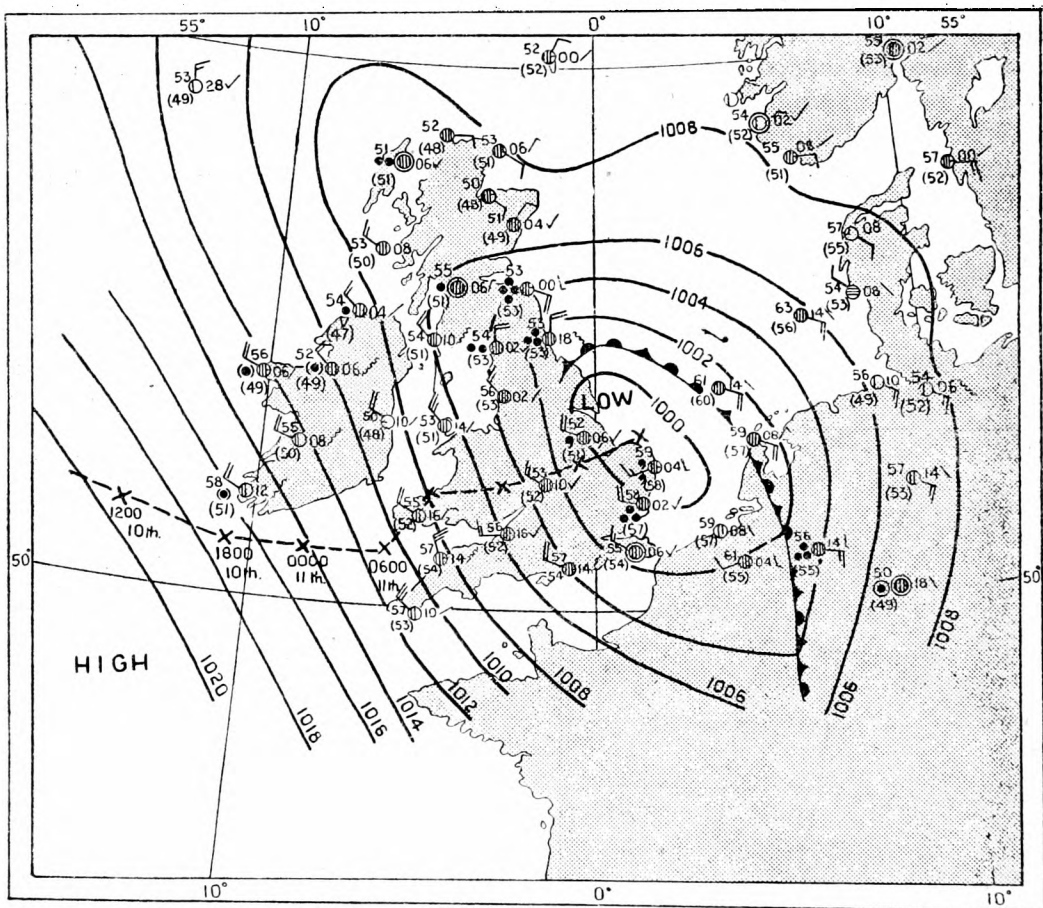


FIG. 2—SEA-LEVEL SYNOPTIC CHART, 0600 G.M.T. AUGUST 12, 1948
The chart shows temperature, dew points (in brackets), weather and barometric tendency; the track of the depression is included

warm-front type, whereas on the continent it was of cold-front type. Most summer occlusions on the continent are of cold-front type, but in the open sea at all seasons there is a natural tendency for the characteristics of a curved occlusion to vary along its length. In this case the depression had been occluded since August 9 and the air, which had ascended from its warm sector, had passed well to southward of the British Isles. The maritime-polar air behind the occlusion had crossed a warm sea area to the south of Ireland and had then gained heat and moisture over England. The water-vapour content of the column of air was not outstandingly high for the time of year, and had

been exceeded on a number of occasions in the preceding fortnight. The air over northern districts ahead of the occlusion had originally formed part of a cold northerly air stream over the Norwegian Sea on the 10th.

Late on the 11th thunderstorms with heavy rainfall developed in the Midlands, behind the occlusion, close to the centre of the depression. These must have contributed to the building up of a thick cloud system extending to the tropopause (about 34,000 ft.) and since the air in which the thunderstorms formed afterwards ascended at the front, this development must have added to the intensity of the rainfall. The tephigrams for Leuchars on the 12th (Fig. 1) showed that frontal action had produced a thick stable layer, and that the rainfall was by then of purely frontal and not of instability type. Leuchars

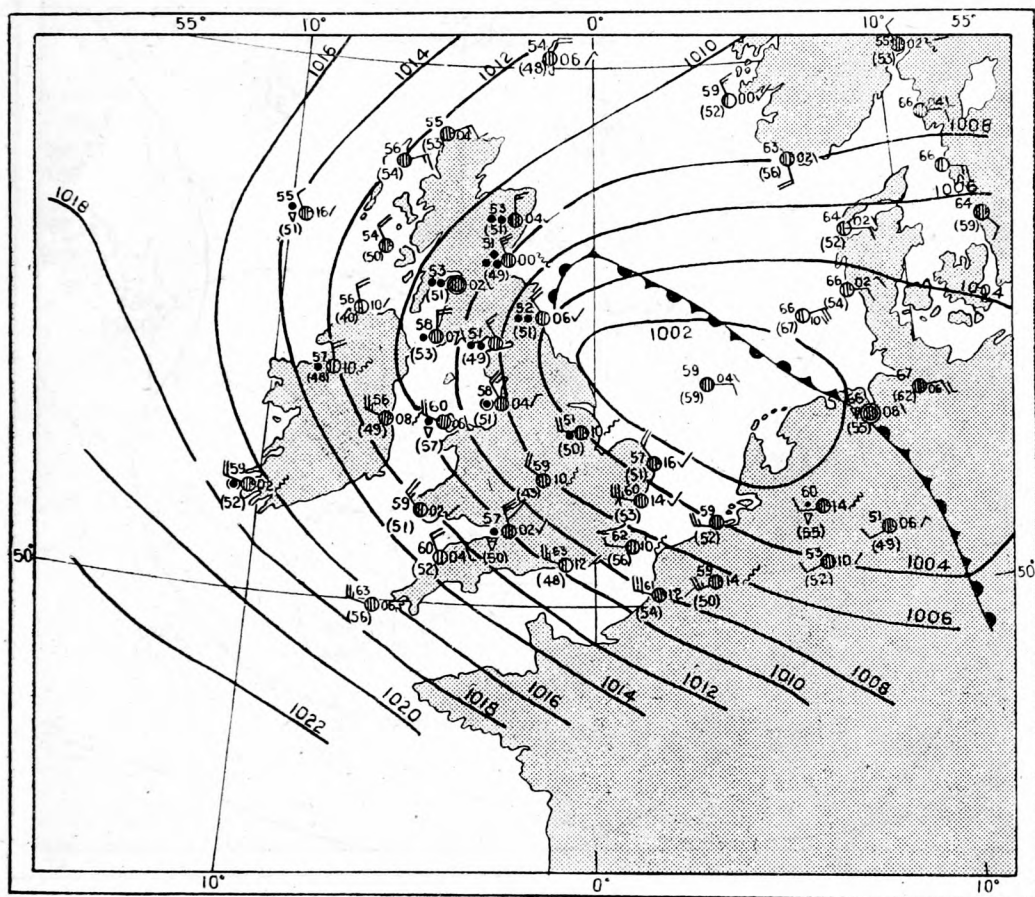


FIG. 3—SEA-LEVEL SYNOPTIC CHART, 1800 G.M.T., 1948

had 32 mm. of rain between 0900 and 2100 on the 12th. This station is about 55 miles north-north-west of the region of maximum rainfall round Kelso.

By 0600 on the 12th (Fig. 2) the area of heavy rainfall had moved northwards to Northumberland and Berwickshire. By 1800 (Fig. 3) it had moved a little to north-west and had begun to weaken, and turn west to south-west. There was further considerable rainfall in south-west Scotland during the night. One can deduce from the tephigrams that the occlusion advanced slightly, but it never reached the coast at sea level and there were no observations to show its exact position.

Figs. 4 and 5 show contours of the height of the 700-mb. surface (continuous lines) and of the 1000-700-mb. thickness (broken lines). The absolute heights are plotted above the thicknesses. The wind direction at 700 mb. is shown by the continuous arrows, and the velocity in knots by the figures in the circles. The broken arrows and the figures at their tails are the vector differences between winds at 950 and 700 mb., closely related to the thermal winds. Temperatures at 700 mb. are also plotted.

The thickness lines indicate the distribution of mean temperature in the 1000-700-mb. layer. There was a warm tongue over and east of the occlusion and a large cold tongue on the south-west side of the depression, and probably a small cold pool near north-west Ireland. This cold air had moved south-east

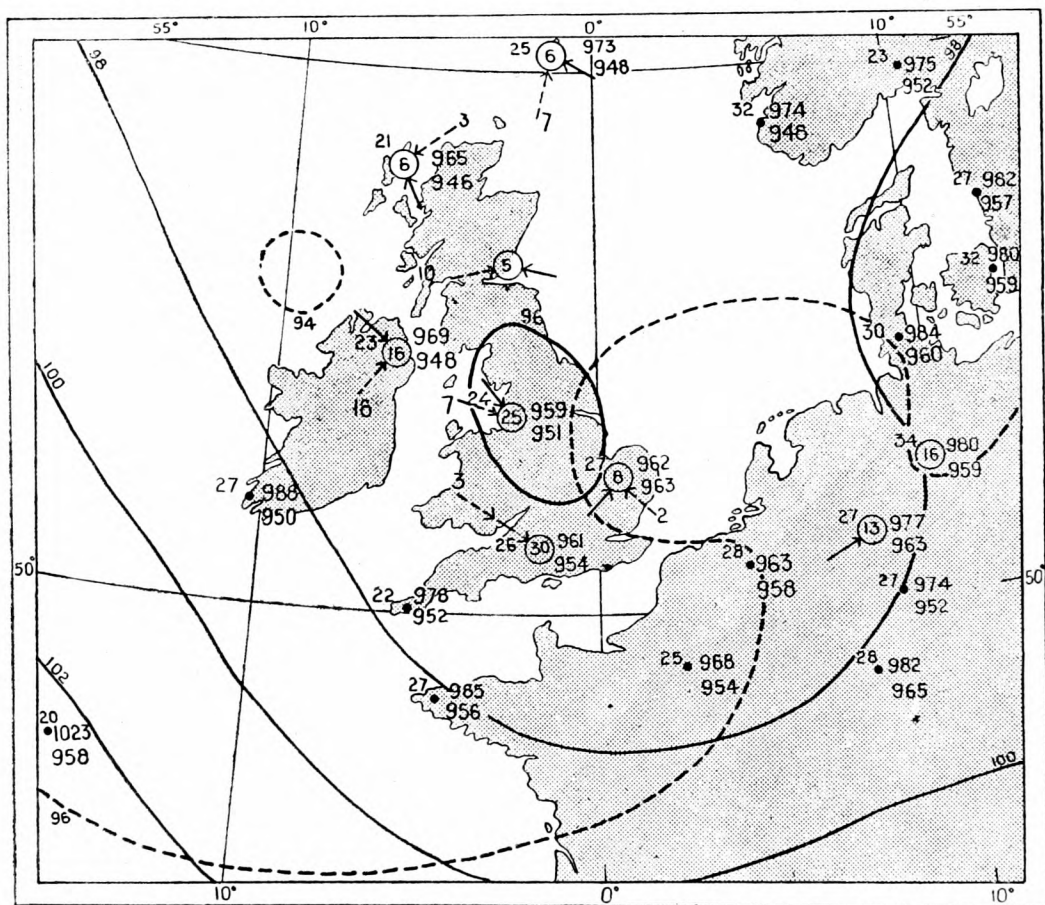
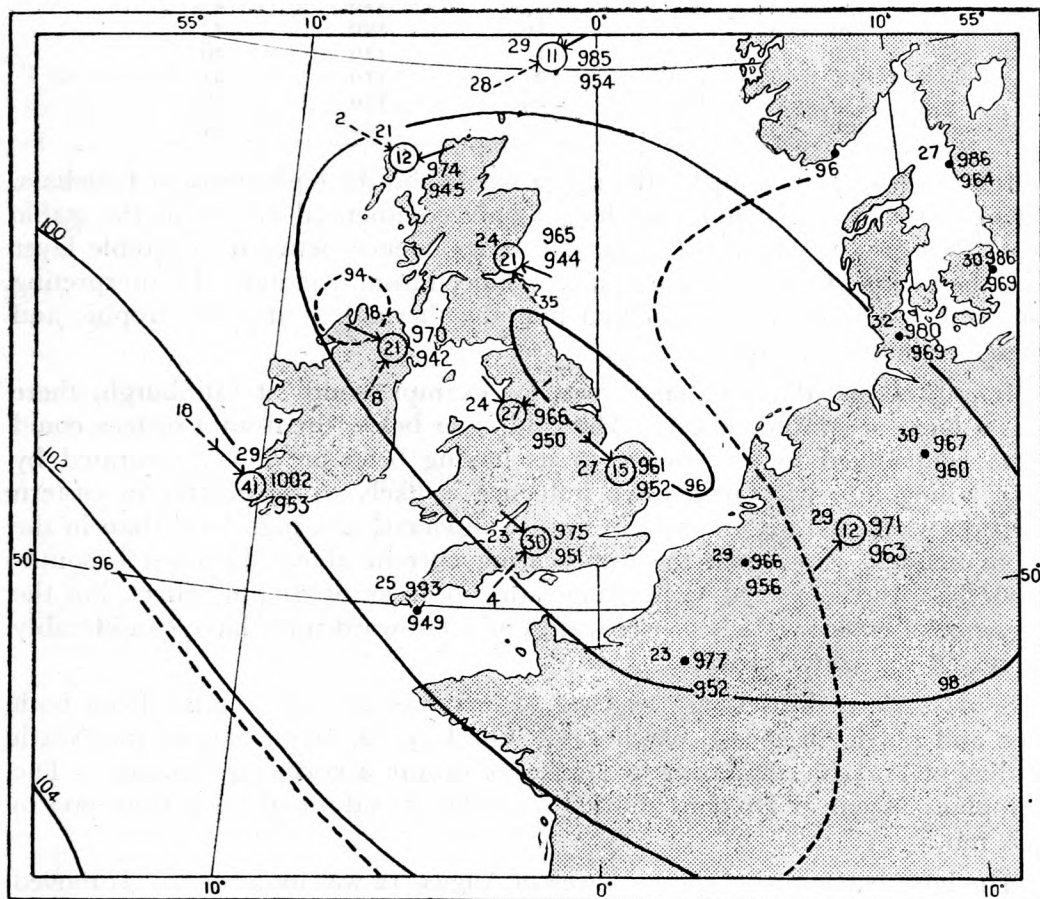


FIG. 4—700-MB. CHART, 0300 G.M.T., AUGUST 12, 1948

The chart shows contours (full lines) and thicknesses (broken lines) at intervals of 200 ft. (For further explanation see above)

from west of Iceland for reasons initially independent of the depression which crossed England. It belonged to a cold depression which moved south-west from Iceland and filled up off the Hebrides, where there was a bulge in the isobars at 0600 on the 12th (Fig. 2). A cold front at the south-east boundary of this current crossed our south-west districts and France, but there was no front separating it from the equally cold air mass to the north of the depression, part of which came round the rear of the depression at low levels. The new cold outbreak gave rise to over-running cold air at the centre of the depression and

thus to instability. It also led to the backing of the upper wind, which carried the rain into Scotland. There was no easterly wind component at 700 mb. observed anywhere up to 2100 on the 11th, and even at 0300 on the 12th (Fig. 5) the east component was still very weak. The upper wind advected the moisture and indirectly added to the intensity of the rainfall, through its effect on the field of acceleration. A trough extended north-west from the centre of the depression, the gradient for NE. wind steepened over Scotland, and the cold air was accelerated to the south-west, with a resulting ageostrophic movement towards south-east. The Leuchars winds, tabulated below, show an increase of velocity low down between 0900 and 1500, and at 1500 the wind at 900 mb. was backed some 20–25° from the sea-level isobars. This involved an ageostrophic wind



slight fall of pressure spreading north and then north-west from the main depression was probably the most important cause of convergence.

The upper winds over Leuchars were as follows:—

Pressure	0900 G.M.T.		1500 G.M.T.	
	Direction	Velocity	Direction	Velocity
mb.	°	kt.	°	kt.
950	050	16	020	23
900	060	17	020	27
850	060	17	030	25
800	030	16	060	21
750	350	18	090	18
700	010	15	110	21
650	050	9	120	23
600	050	10	120	27
550	120	14	110	26
500	130	24	110	24
450	150	29	130	28
400	140	34	140	34

It is interesting to compare the upper winds and the tephigrams at Leuchars. At 0900 the veer of wind with height only commenced far up in the stable layer, but at 1500 there was a good correspondence between the stable layer and the region of veer, indicating a pronounced frontal action. In interpreting this action it must be remembered that the thermal wind is geostrophic and therefore non-divergent.

It is probable that in some areas, for example south of Edinburgh, there was a large orographic effect. The cold layer below the frontal surface could have contributed to this, owing to its having been previously saturated by rain falling into it. Orographic influence is likely to be greater in eastern districts when there is an easterly wind component to a high level than in the more frequent case when the rain-bearing current above the front is south-westerly. In the Tweed Valley there was no direct orographic effect, but the presence of extensive hills to westward and southward must have considerably increased the convergence.

Some eastern districts are exposed to heavy orographic rainfall from both east and north, in special conditions. On July 22, 1930, part of the North Riding of Yorkshire had over five inches of rain in a northerly situation. The aeroplane ascent at Duxford showed a stable but saturated layer from 900 to 500 mb.

The later behaviour of the rain area of August 12 was interesting. It moved south-west to the Irish Sea and then south-east across the Midlands on the 13th, thus making a complete circuit round the slowly moving 700-mb. centre. Rainfall amounts were small on the 13th, but 0·12 in. fell at Croydon and Felixstowe. The upper wind backed in Scotland and weather was fine and sunny on the 13th. The last appearance of the depression as a separate centre was off Helder at 1800 on the 13th. It degenerated to a trough in the circulation of a new system over Poland and moved south.

To sum up, the phenomenal rainfall was due to an exceptional combination of factors and cannot be adequately explained even after the event. The probability of recurrence of this particular combination of circumstances is clearly very small. Excessive rainfall could be produced by developments different in detail, but as is mentioned in Dr. Glasspoole's note, the largest

fall previously recorded in that area was very much less, and the chances of six inches of rain in a day in any area are always exceedingly small. The Norwich rainstorm accompanied a depression which deepened to 978 mb. close to the region of maximum rainfall, and which produced gales near its centre. The Bruton rainstorm was related to a shallow depression moving slowly east in the English Channel. The Tweed rainstorm differed from either of these in that the main cyclonic centre was 250 miles off and developed a temporary protrusion towards the north-west.

CHINESE "RAININESS" THROUGH THE CENTURIES

By D. JUSTIN SCHOVE, B.Sc.

The meteorological annals of China are far more detailed and extend much further back in time than those available in European chronicles. The dating of the events has been checked with reference to the known dates of Halley's comet since at least 87 B.C. and of eclipses since 720 B.C.

Most of the meteorological events from 206 B.C. to A.D. 1634 were listed in the T'u-shu Chi-ch'eng (Section IV: "Strange phenomena" chuan 86-92; 124-130), which is available in the British Museum and in the Bodleian Library. This was completed in 1726 and may indirectly have inspired Dr. T. Short and Pilgram to make, later in the century, similar but less accurate lists for Europe. Subsequent Chinese events have been included in the "Treatise on calamities and anomalies", Chapters 40 and 43 of the Ch'ing Shih Kao.

Extracts from the "Strange phenomena" in the great encyclopædia have been made and incomplete lists of floods, droughts, comets, auroræ, sunspots, shooting stars and eclipses in China have been published in England and France during the past two centuries. Statistical interpretation of the data has, however, been begun only recently and that has been initiated by the Chinese themselves. The pioneer in this field is Dr. Coching Chu (President of Chekiang University) who, on the basis of the recorded number of floods R and droughts D calculated^{1,2*} a raininess factor D/R for each century (cf. Brooks³). Yao^{4,5,6} has now extended this investigation, and has used the two above-mentioned sources to obtain more detailed information.

In Fig. 1 curves have been drawn to illustrate the various indices of raininess. The data of Yao and Chu are represented by curves (1) and (2) respectively. Curve (3) is based on an earlier selection of data by Hosie^{7,8} which is very inadequate as far as floods are concerned, but is included to indicate half-century tendencies.

The agreement between the curves (1) and (2) is striking but deceptive. Both curves also agree, at least to A.D. 600, with curve (4); this curve is not an index of "raininess" at all but rather an indication of the total amount of regional information available since it represents the total of all floods and droughts in Yao's regional tabulations (Table XI). It is evident that when local records are least complete, as in the fourth and sixth centuries, floods rather than droughts tend to be omitted. In Europe a similar tendency can be observed.

*These numbers refer to the list of references on p. 15.

The belief in progressive dessication has not been supported by recent investigations either in Africa or China, except inasmuch as it is a consequence of local deforestation. On the other hand the apparent trend towards increased wetness in curves (1) and (2) is equally illusory, and, pending the results of pollen-analysis, must be regarded merely as a reflection of the growth of detailed records. It is for instance particularly noticeable about the second and tenth centuries—centuries associated with the invention and the wide diffusion of paper and printing respectively in China.

An attempt has been made in Table I to correct for the variability of record by a simple formula. A more refined method of correction, such as used by Brooks and Glasspoole for Europe⁹, may be possible when fuller data are available.

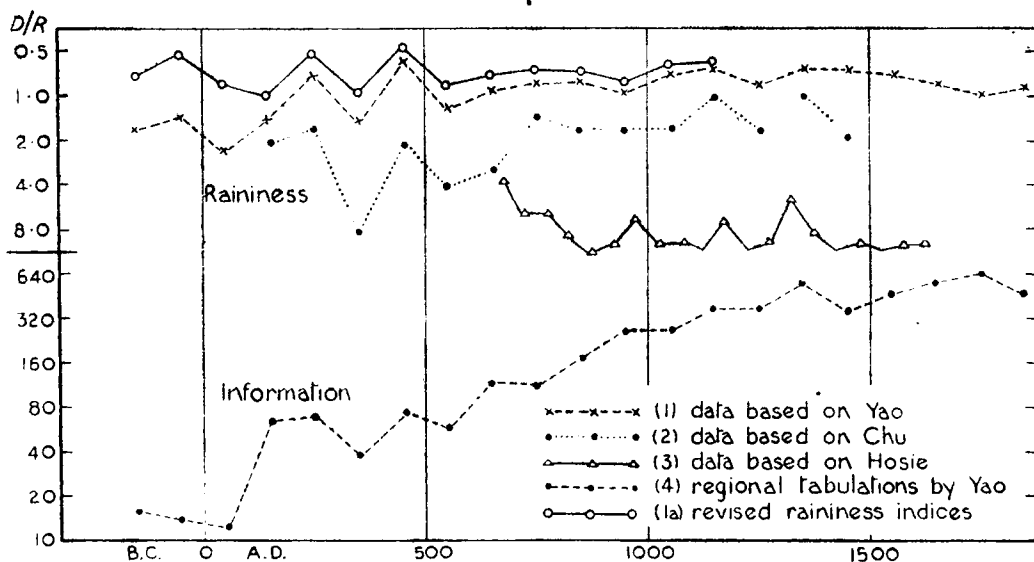


FIG. 1

The revised "raininess indices" (defined in Table I) are shown in the top curve (1a), but I do not regard even this as satisfactory evidence of climatic variations. The variations reflect rather the changes of capitals, canals and rivers. Analysis of eclipses in the same encyclopædia indicates that the regions of observation vary, e.g. from 32°N. 119°E. in the fourth century to 40°N. 116½°E. in the fifteenth, i.e. regions as far apart as Venice and Antwerp. As Yao stresses, the information is most complete from whichever areas were economically important at the time and, from the seventh century, when the east coast became densely populated, the information is more complete for this region than for that of "China's sorrow", the Yellow River.

The flood and drought data were next classified according to Mallory's three regions—north, central and south China, which partly disposes of the above objections. The corresponding regional raininess indices are plotted in curves (5) to (7) (Fig. 2). Once again the trends are deceptive, but this time the trends appear to be towards increased dessication—merely because in early centuries the location of droughts was often unspecified.

The test of consistency suggests that the third, eighth and eleventh centuries are wet and that the fourth and twelfth are dry. Nevertheless, preliminary

TABLE I—CORRECTION FOR VARIABILITY OF RECORD

Century	Curve (1)	Curve (4)	Curve (1a)	
	DRYNESS RATIO*	REGIONAL INFORMATION*	" DRYNESS " (corrected)	RAININESS INDEX
	$d = 100 \frac{D}{R}$	n	$d - df$ where $f^2n = 5$	$7 - \frac{d(1-f)}{10}$
B.C.				
2	175	15	73	+0
1	144	13	55	+2
A.D.				
1	236	12	85	-2
2	144	66	102	-3
3	77	68	56	+1
4	154	37	97	-3
5	65	74	47	+2
6	129	58	92	-2
7	94	124	75	+0
8	86	116	68	+0
9	83	186	70	+0
10	96	262	83	-1
11	71	264	61	+1
12	67	389	60	+1
13	86	368	76	-1
14	66	564	60	+1
15	69	351	61	+1
16	73	435	65	-0
17	87	561	78	-1
18	103	632	94	-2
19	93	410	83	-1

*According to Yao.

studies have shown the rainfall deviations of different parts of China are related in different ways to world weather, whilst many of the spring floods are thaw floods and associated not with rains but with cold winters. It is probably significant that the three centuries selected as "wet" were ones in which civil strife allowed the canals to fall into disrepair as shown in curve (11), Fig. 4.

The need is clearly for smaller units not only of space but also of time. In the latter respect Yao's tabulations by quarter-centuries yield curve (8) (Fig. 3), which is probably the most significant of all the curves. This curve is derived from the data in Yao's Tables V and VI, but his regional and provincial data are published by him for periods of at least a century. Regional studies of river floods are being made, the most important being that of the Hwang-ho by Shen¹⁰ and Kohler¹¹, that of the lower Yangtze-kiang by Cheng¹² and Chatley¹³,

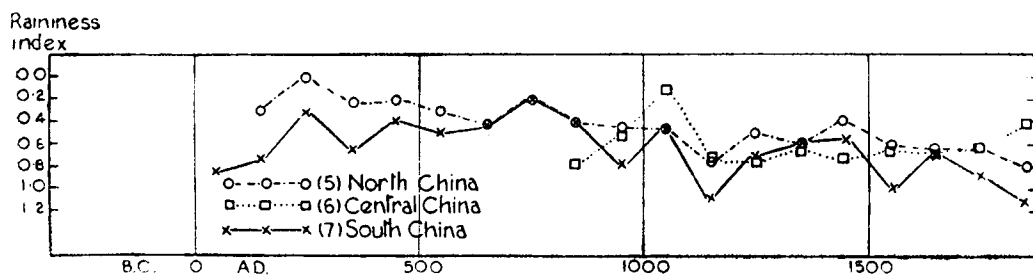


FIG. 2

and of Shensi by Ting¹⁴. It is anticipated that chronologies on the lines of C. E. Britton's work for England¹⁵ will soon become available for different cities and provinces; thus a study of Peking's climate for the past two centuries has been made by T. C. Cheng¹⁶.

China's north-west passage between the Tibetan plateau and the Gobi desert, also known as the Jade Gate or the Silk Road, is the one gateway to central Asia. A graph indicating the fluctuations of travel along this route is given as curve (9). Whilst the main features of such a curve must necessarily remain partly subjective, the details are based on many hundred archæological and historical sources and it was drawn before knowing Yao's results. Another such curve based on travel in the Syrian desert (Grant¹⁷) is also given as curve (10). The units are arbitrary.

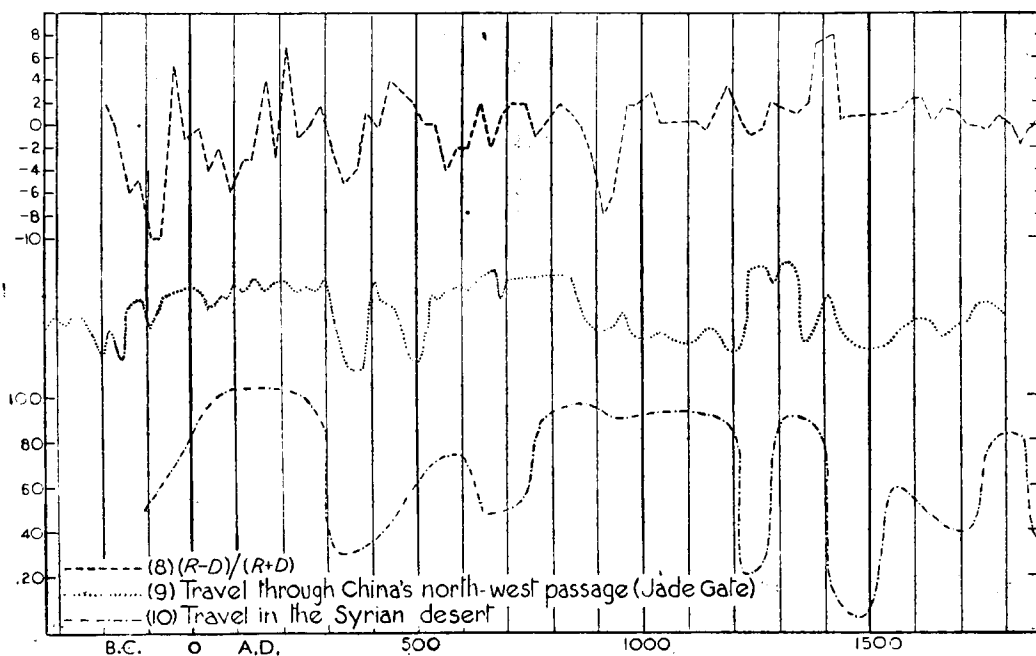


FIG. 3

The late Prof. Huntington, originally in a book "The pulse of Asia" and more recently in an illustrative graph¹⁸, stated that the wet periods in world history are those such as the fourteenth century, when Asiatic and Syrian desert trade was high, Irish civilization low and growth of trees at a maximum. Nevertheless, the disagreement between the curves given here extends equally to curves for tree-ring growth, and other climatic curves. In particular, Huntington selects the seventh century as the driest on the evidence of lakes and ruins in Asia; this is however the very century when central Asian travel broke all previous records, when Christians, Zoroastrians, Manichæists and Moslems passed to and fro across the Tarim Basin. On the other hand the abandonment of many sites has been traced to the early fourth century which does appear to have been remarkably dry and was certainly marked by great southward migrations across China.

Curve (11) (Fig. 4) shows the civil wars and is based partly on J. S. Lee's chart of internecine warfare (reproduced by Yutang¹⁹). Such strife affected the dyke system and crops inside China and also travel along the silk road outside.

Curve (12) is an attempt—in accordance with a suggestion of Dr. C. E. P. Brooks—to represent the population movements in north China between the Steppe and the Sown. It is however easy to list specific nomad incursions (see Toynbee²⁰ or the map by Griffith Taylor²¹—whose dates are indicated by crosses below the curve) but sometimes the real population movement was in the reverse direction. In the thirteenth-century Mongol incursions, for instance, settlers went from the Sown towards the Steppe. Population dot maps, such as published by Bielenstein²² based on early data, are invaluable, but archæological research shows that such information is too erratic in the north-west to use in a graph. A combination of various lines of evidence was used in the preparation of curve (12) but it will need revision in the light of future archæological research (see Stein²³).

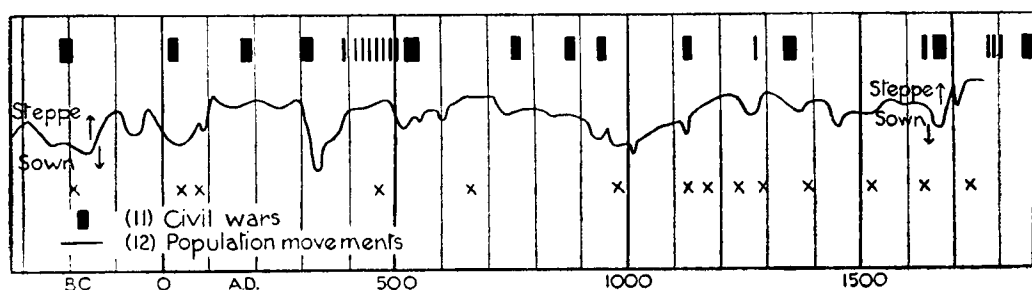


FIG. 4

In his 1944 paper, Yao stresses the limitations of the basic data in both his sources and says of the encyclopædia that, whilst it is a "convenient starting point", it is "adequate only for very general purposes". Nevertheless, as he has deposited the complete list of floods and droughts (with two microfilm copies) in the Pennsylvania University Library, his work is an excellent base from which more detailed investigations can be made. Another independent list of floods and droughts, used by Cheng¹², was published in Volume 7 of the Nanking Chinese Library *Annual Bulletin*, but that does not appear to be available in this country.

Summarising, curves (4), (9), (10) and (11) are generally reliable, curves (8) and (12) partly so. The remaining curves are interesting, but we must await independent lines of evidence before we can judge their significance. A further review of the same data can then be made.

In conclusion I should like to thank Dr. C. E. P. Brooks, Dr. Herbert Chatley, Dr. Coching Chu and Professor H. H. Dubs for useful suggestions.

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METEOROLOGICAL OFFICE DISCUSSION

October 25, 1948. On the distribution of temperature and wind in the upper westerlies, by E. Palmén (*J. Met., Lancaster, Pa.*, **5**, 1948, p. 20). Opener—Mr. J. M. Craddock.

Mr. J. M. Craddock stated that Palmén's line of attack had been to examine a series of vertical cross-sections through the atmosphere along the meridian of 80°W. The 16 upper air stations on or near this line gave information adequate for the analysis of fronts, tropopause and inversions, besides the isotherms, but that the analysis of upper winds normal to the plane of the cross-section was based on computed slopes of isobaric surfaces and on the assumption of geostrophic or gradient air flow. Thus in view of the, not negligible, observational error of the radio-sonde and the difficulty of determining the curvature of the air flow, the exact wind structure at a particular time could not be determined although the general picture was clear enough. From a series of charts covering the winter of 1946-47 Palmén reached the following conclusions as to conditions characteristic of an upper trough (but applicable also in other situations).

(1) The tropopause could not be considered as a continuous surface of discontinuity of lapse rate, but that three different tropopauses could be traced, characterised by quasi-entropy. Palmén's illustrative cross-section was not conclusive, but in work with more extensive data in a later paper he had put the matter beyond doubt.

(2) The arctic stratosphere in the time of no insolation was always very cold—at the 200-mb. level the temperature field shows a cold arctic zone, with a warmer ring between 45° and 65°N., a second ring of low temperature south of the jet stream, and then increasing temperature south to the equator.

(3) Often there is a region of lowest temperature in the troposphere and highest in the stratosphere in latitudes 45-65°N. Mr. Craddock thought that

while this distribution was characteristic of the later stages of an active depression near the line of the cross-section it was not prevalent in other synoptic situations, and should be looked on as rather exceptional.

(4) The contrast in temperature between the equatorial and polar regions is in the mean troposphere and largely concentrated in a rather narrow band, which is also the zone of strongest westerlies. Mr. Craddock considered this an important and very common feature of the upper circulation, although the wind belt often departed from the westerly, and tended to be wider and less intense over the eastern North Atlantic and British Isles than over North America. In many major cold or warm outbreaks the wind belt formed a sinuosity which is liable to separate, as a closed pool, to south or north of the main belt.

(5) The strongest west wind, exceeding 80 m./sec. in Palmén's example, can regularly be observed vertically above the latitude where the polar-front layer reaches the height of 600–500 mb. Below this level the horizontal wind shear is rather weak, and above this belt the air moves as a narrow "river" with the strongest speed in the tropopause level. This zone of wind can be characterised as a "jet stream" embedded in the upper westerlies. The illustrative cross-section did not, in the absence of actual wind observations, establish the existence of this feature beyond doubt, and Mr. Craddock produced a cross-section crossing the British Isles in which a jet stream could be identified from the observed wind values. He thought that the jet stream bore a less definite relation to the surface polar front than Palmén suggested and that a jet stream over the British Isles was often north-westerly or even northerly.

Palmén examined the dynamic stability of the air flow in the zone of anticyclonic wind shear to the south of the centre of the jet stream. The shear of the geostrophic wind exceeded the limit below which the air flow was dynamically stable, but he was unable to ascertain beyond doubt whether the actual wind did so. After further consideration in a later paper he concluded tentatively that except possibly in zones less than 300 Km. wide, the shear did not exceed the critical value.

Finally he showed that, where a warm air mass with strongly anticyclonic wind shear was adjacent to a weak front, the latter might show anticyclonic shear at the 700-mb. level.

Commenting on the paper as a whole, Mr. Craddock said that three features, the multiple nature of the tropopause, the cold polar stratosphere at mid-winter, and the concentration of the thermal gradient between equator and pole into a fairly narrow band were important descriptive features of the winter circulation. The jet stream was the feature most likely to arouse controversy, and one very important to the forecaster. The eastern part of North America in winter was a very favourable position for its development, because the geographical distribution did not impede the near approach of warm and very cold air masses. Over the British Isles a jet stream was most likely to arise when there was cold air over the continent and warm over the Atlantic. Upper westerly winds of very high velocity were also regularly observed over north India in winter. As to the theoretical significance of the jet stream, Palmén's conclusion to a later paper may be quoted. "A definite explanation of the temperature field and the extremely strong latitudinal change of shear (and vorticity) has still not been found. It is obvious that the appearance of the very strong westerly

current in the upper troposphere, the formation of a distinct frontal zone below and the characteristic temperature field at the tropopause level are phenomena related in some fashion."

Sir Nelson Johnson opened the discussion by asking how a forecaster could recognise the presence of a jet stream.

Mr. Durst said that as soon as it was realised how important the phenomenon might be in navigation an investigation was put in hand to see how jet streams behaved over the British Isles. The result was a paper which was coming before the Meteorological Research Committee. On the whole the tendency was for jet streams to lie north-west to south-east rather than west to east; they were quite common somewhere or other on the synoptic charts of Europe and the North Atlantic; they were of the order of a thousand miles in length and three or four hundred miles in width. On the polar-air side of the centre of the jet the spatial rate of change in wind speed was very great, sometimes the wind speed fell from 130 kt. to 30 kt. in a hundred miles. The importance to navigation was obvious and was emphasised by the recent case of the Vampires flying to Iceland when the frequency of equivalent head winds had been calculated on the assumption that wind speeds were as likely to fall off down wind as across wind. This was not true with jet streams. The frequency of very strong equivalent head winds were vitiated but the frequency estimated for the moderate or strong winds was not materially affected.

Mr. N. E. Davis said that jet streams over the British Isles generally arose when polar air flowed south and south-east round a high-level low over Norway and tropical air flowed north-east and east round an extension of the Azores anticyclone, the resultant jet stream being NW. As the slope of a front depends on the difference in wind speed parallel to the front, as well as inversely on the difference of temperature, the front associated with a jet stream gets very steep in its upper levels. This accounts for the extreme horizontal-wind-speed gradient on the polar side of the jet.

Dr. Sutcliffe remarked that these facts about the atmospheric circulation were of first-rank importance, so important that we may be in danger of being carried away by the jet stream, as though it were a new phenomenon not in accordance with known facts and principles. We were, however, familiar with the high-level circulation being generally more vigorous than the low-level and that the high-level geostrophic wind is mainly the thermal wind. Thus, if we think of the atmosphere as a baroclinic fluid with relatively small temperature gradients at both high and low latitudes, we should expect the temperature profile to be represented by an inflected curve with a maximum slope corresponding to a maximum westerly wind at high levels. The only surprising thing was the intensity of this maximum in the cases examined, but his own impression was that there were wide variations and that to accept the idea of a jet stream encircling the earth "like a meandering river" we must be prepared to extend the term to weak maxima which themselves would never suggest the term. The essential accompaniment of a jet stream is a strong thermal gradient, a concentration of solenoids, and this will tend to be built up in any generalised frontogenetic region.

We must, however, recognise a real discrepancy between the temperature and wind structures now observed and those associated with the classical polar-front hypothesis. Instead of a gently sloping Margules surface containing most

of the solenoids in a virtual discontinuity we seemed to have a more nearly vertical zone of large thermal gradient in the upper levels with two regions of strong wind shear, one on the cold side and one, anticyclonic, on the warm side. On dynamical grounds it seemed easier to explain this mode of organization of the motion than that of the single sloping frontal surface when we remembered that the strong thermal gradients were continuously being set up in one region and destroyed elsewhere. A frontogenetic process, as in the classical hyperbolic pattern, would tend to concentrate the isotherms, at all levels in the troposphere, in a more or less vertical zone. The necessary modification of wind to pressure gradient implied a flow of air across the upper isobars from the warm to the cold side. This implied also upper divergence (and anticyclonic vorticity) on the warm side, convergence (and cyclonic vorticity) on the cold side. The low-level motion, to complete the cycle, must show convergence to the warm side and divergence to the cold side, in effect an undercutting by the cold air. It seemed likely that the sharp surface front on the warm side of the jet stream was the result of this convergence. On this basis the jet stream itself was transitional air in the zone of strong thermal gradient and it must be rather arbitrary to connect the low-level frontal surface on the warm side of the transition zone with the upper convergence region on the cold side.

It was, however, easy to give plausible comments on observed facts: the merit lay, as so often in meteorology, with those who make the discoveries; and these discoveries were vitally important. As practical synoptic meteorologists we must review our techniques, consider whether we can, by more careful drawing of contour charts, represent more accurately the facts so easily smoothed out. Possible ideas would be to try to run a line of maximum gradient through the upper contour patterns, to represent the intensity of the jet stream by some "jet index", and to attempt to give the forecast position and index in our forecast charts. Information over wide areas may be inadequate but general judgment using models based on cases where data are adequate is the normal technique of all analysis and should not be inapplicable to this aspect.

Dr. G. D. Robinson said that Professor Palmén's results indicated a change of velocity of the order of 100 m.p.h. in 300 miles, whereas Mr. Durst's investigations showed a change of this order in 100 miles. These distances are of the same order as the separation of stations used in the respective investigations. May they not therefore indicate the "resolving power" of the radio-sonde network rather than a real wind structure, and can we say that an increase of this resolving power would not demonstrate a wind discontinuity similar to that expected at the old-fashioned frontal surface? We should not forget that, compared with surface observations, upper air observations are extremely meagre, and that observational techniques and the lack of continuous records at a fixed position tend to mask sudden changes and to smooth discontinuities.

Mr. J. S. Sawyer remarked that Palmén's intention was to study the zonal atmospheric motion. The jet stream appeared above the polar front in latitude 30° to 40° N. and similar phenomena were found above fronts elsewhere; on the other hand, maps of the mean circulation show a strong belt of upper westerlies in subtropical latitudes, but whether these show the same features elsewhere as on the American coast is not known. However, the term jet stream has been applied to both the local frontal phenomena and the broad feature of the hemispherical circulation; there is thus a risk of confusion.

Mr. Bannon pointed out that the jet stream is associated with strong horizontal temperature gradient and that he had found that, around Britain, with any well marked front there was an associated jet stream of greater or less intensity. It was of interest that, in November 1947, a jet stream occurred over or near the British Isles on 16 consecutive days. He also pointed out that the gradient of wind across the stream was not necessarily a true measure of the horizontal shear (as had been assumed by previous speakers) because of the possible curvature of the stream lines.

Mr. C. K. M. Douglas remarked that the existence of very strong currents at cirrus levels in belts a few hundred miles wide more or less parallel to a major front had long been recognised. Recent observational advances have led to a more detailed knowledge of the structure of these currents.

A suggestion had been made that the Central Forecasting Office smoothed upper contours too much. This is not altogether avoidable in the case of forecast contours, especially 24 hours ahead. When large changes are in progress it is difficult to fix the exact future position of a jet stream, which does not necessarily remain at a fixed distance from the associated front especially when cold air is subsiding and spreading out.

Mr. B. C. V. Oddie said it was somewhat alarming that this important phenomenon has evidently been known vaguely to many forecasters for some years without coming to light. It was first brought to his notice in 1945 when a NOCTURNAL aircraft was carried nearly 100 miles from its expected position while flying above a cold front. Since then he had made a practice of indicating in route forecasts a narrow belt of strong winds parallel to and above a front. These forecast winds must have been very inaccurate, but at least warned navigators against assuming the winds over a front to be merely intermediate between those on either side.

Mr. Dight, agreeing with Dr. Sutcliffe's cautionary note, said that these high-speed winds were recognised and had been indicated to forecasters on practical training courses for a long time. The advice was that the winds probably occurred only in a narrow belt and did not appear to persist for long over a given locality, points for consideration when forecasting for long- or medium-range flights. The tentative explanation given was the "bunching" of the isotherms in the upper air frontal zone, usually with the distribution suggested by a previous speaker giving NW. to N. winds over Britain.

Dr. Belasco wondered to what degree the horizontal temperature gradient influenced a jet stream and referred to upper-air conditions over the British Isles at 0600 on February 8, 1946, when a quasi-stationary warm front extended westwards from Belgium to Ireland. Whereas the wind direction (between 280° and 290°) at all stations in the warm air rapidly increased with height in the layer from about 450 mb. through the tropopause to above 200 mb. (e.g. at Downham Market from 77 kt. at 500 mb. to 198 kt. at 170 mb.) the temperature gradient normal to the front above 400 mb. became reversed. Thus in the same air mass the temperature difference between Downham Market and Lerwick at 0600 was $+21^{\circ}\text{F.}$ at 400 mb. and -16°F. at 170 mb., between Brussels and Leuchars at 1200 was $+17^{\circ}\text{F.}$ at 400 mb. and -15°F. at 200 mb. and between Liverpool and Stornoway at 0600 was $+10^{\circ}\text{F.}$ at 400 mb.

Dr. Belasco said he had found the temperature contrast between subtropical and polar regions in the troposphere greatest about midway between them and quoted from his thesis on "The temperature characteristics of different classes of air" (1947) that, along about 10°W . the difference between the mean temperature of tropical and direct polar air at 450 mb. in winter is 50°F . between 51°N . and 57°N .

Mr. T. H. Kirk remarked that like many other ideas in meteorology, that of the jet stream derives from oceanography. Ocean currents, of which the Gulf Stream is the best example, are analogous to the jet streams of the atmosphere. The dynamical problem must be simpler for ocean currents inasmuch as stationary fields can be assumed. Rossby has already given some account of the problem in his paper "The dynamics of steady ocean currents".

The Gulf Stream, together with its extension, the North Atlantic Drift, maintains its identity over thousands of miles, and we have heard that jet streams can exist over comparable distances. The very mechanism of self-maintenance over such distances constitutes a real dynamical problem. Another aspect which is important derives from the existence of a velocity profile across the jet stream. This means that we must look for an explanation elsewhere than on the usual equations of motion for frictionless flow.

Mr. Sumner thought that its connexion with dynamic instability was of greater interest. If dynamic instability is ever reached it will be realised at one height only and over a limited area; the shearing across the layers above and below make eddying probable which, once started, would infect a wider and deeper layer downwind. If this is so then first it might explain the severe bumpiness sometimes met at great heights by aircraft even in clear air and secondly why the Rossby effect of anticyclogenesis to the right of a strong westerly current due to lateral shear stresses does not seem to work very often. To produce an anticyclone and not simply subsidence larger eddy viscosities than normal may be required.

Palmén remarks that mean charts do not show a jet, which reminds us that the general circulation is not simply the mean circulation of the atmosphere. A climatic mean does not represent a physical reality, and, since the equations of motion are non-linear, the mean circulation does not represent a real process. The jet stream is one of the features which is meant out of existence. *Mr. Sumner* could not offer any explanation: to him, the confluence of stream lines seemed only to explain local tight gradients; however the subsidence associated with anticyclonic vorticity may maintain a tight thermal gradient all the way round the periphery of a warm ridge in spite of the tendency of lateral mixing to reduce it.

Mr. G. J. W. Oddie referred to the theory put forward in earlier papers by the Chicago University Group regarding the extent and direction of the jet stream. According to this the jet stream marked the transitional belt between the régime of the polar cap in which the westerly component of the wind increased towards the equator owing to a tendency for lateral mixing to produce uniformity in the vertical component of absolute vorticity, and the régime of the equatorial belt in which the westerly component of the wind increased towards the pole, owing to a tendency for lateral mixing to produce uniformity of absolute angular momentum. The jet stream would thus be expected to encircle the globe in middle latitudes meandering northward and southward

as the relative activity of the two régimes varied. Circumpolar upper-air charts included in these papers had shown four or five complete waves round the earth between 30° and 50°N. , the direction of the stream varying from S. through W. to N. Another interesting suggestion appearing in these papers had been that increased velocities in one wave could lead to the by-passing of the next which was then isolated as a "warm high" if on the north side of the stream or as a "cold pool" if on the south side. Mr. Oddie asked if all these ideas had been dropped in the latest papers. With reference to Mr. Craddock's suggestion that more had been drawn into Palmén's cross-sections than the observations justified, Mr. G. J. W. Oddie asked if we could not assume that Palmén had worked, not from one set of synchronous soundings, but from a series of sets.

Mr. D. G. Harley pointed out that if an aircraft crossing the Atlantic meets a jet-stream wind head-on and unforecast, the result may be fatal. London, Prestwick and Shannon airports have to forecast these winds on the other side of the Atlantic up to 24 hours ahead. The thermal-wind idea is still most useful but leads to considering the upper winds as secondary to the surface situation. We need to develop new methods of forecasting from our new knowledge of the upper circulation, but cannot just suddenly drop the present methods based on long experience of surface conditions. The concept of momentum—masses of air in motion—is most important.

Commander Frankcom hoped that steps could be taken to introduce this subject at a discussion at the Institution of Navigation. The discussion had emphasised the necessity of a reasonable network of observations and this probably applied particularly to the Atlantic Ocean where long-distance air traffic was so heavy. Possibly the existence of 13 ocean weather stations would ensure detection of such high-velocity wind zones. This might provide a good argument in favour of the retention of weather ships, when the situation is reviewed by I.C.A.O. next spring.

Mr. R. T. Andrews said there was evidence for periods of very strong upper currents (for which he did not consider "jet stream" a very suitable term) in the nephoscope observations contained for many years in the *Daily Weather Report*. He was very doubtful whether the normal direction of the jet stream over the British Isles was north-westerly and thought it was more frequently westerly. He also doubted if it occurred as a belt right round the hemisphere and suggested it was both narrow in width and limited in length, being normally concentrated on the south side of a cold pool.

In reply, Mr. Craddock said that the term "jet stream" seemed to be used to cover two things, a zone of more or less intense thermal gradient, which often extended round the hemisphere, and secondly, the narrow zone of extremely high winds near the tropopause level which sometimes accompanied an intense thermal contrast. He thought that the term should be restricted to the second sense, in which Mr. Durst had used it. In reply to Dr. Belasco he said that his example was most interesting, but that the stations of Downham Market and Lerwick were too far apart for use in estimating the local temperature gradient near Downham Market. In reply to Mr. G. J. W. Oddie (partly communicated) the basic theory mentioned was not used in the present paper, but the cutting off of warm and cold pools is a common occurrence of obvious importance in the general atmospheric circulation. He did not know whether

any satisfactory explanation had been published. Regarding Palmén's technique, the use of a series of cross-sections would confirm the general picture, but would not establish in an individual cross-section a feature liable to rapid fluctuations (such as a local wind maximum, or a tropopause) if the synchronous data were inconclusive.

METEOROLOGICAL RESEARCH COMMITTEE

The third meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on November 4, 1948. Methods of attacking the problem of forecasting fog were discussed; officers at out-stations who have volunteered to assist in fog investigations will form a working party under Dr. Sutcliffe to tackle this problem.

The direction of research in extended forecasting was also discussed and it was decided that for the next year, at least, the available effort in the Forecasting Research Division should be concentrated on the medium-range problem (i.e. forecasts for 4 to 5 days ahead) which may be tackled by an extension of present forecasting techniques and whose study should prove very useful when the problem of forecasting for much longer periods comes to be considered.

Other matters discussed by the Sub-Committee were statistics of wind, the phenomenon known as a "jet stream" and a mathematical method of analysing pressure fields suggested by Professor Sperner as an approach to the long-range forecasting problem.

OFFICIAL PUBLICATIONS

The following publication has recently been issued:—

Cloud Forms, 6th edition.

This publication gives a detailed description of the internationally agreed classification of cloud types revised to agree with the decisions of the Washington Meteorological Conference of 1947. It gives at least one and often three photographs of each type of cloud. Readers familiar with the earlier classification should note that important changes have been made, especially in the classification of low clouds. This is the first publication to give an illustrated description of the new classification.

ROYAL METEOROLOGICAL SOCIETY

The meeting of the Society, held at 49 Cromwell Road, on November 17, Dr. G. M. B. Dobson in the Chair, was devoted to a discussion on the physics of clouds, and was concerned almost entirely with ice particles.

The discussion was opened by Mr. Ludlam, who outlined recent work on atmospheric ice nuclei and its application to the interpretation of cloud forms and transformations. The old conception of sublimation nuclei (solid, insoluble particles isomorphous with ice and allowing condensation direct from vapour to crystal at ice saturation) was introduced by A. Wegener, and developed by Findeisen. In 1939 Krastanow, however, attacked the problem on a sounder theoretical basis, and emphasised that such solid particles as occur

in the atmosphere obtain microscopic skins of adsorbed water at high vapour pressures and tend to produce supercooled droplets rather than crystals even at temperatures far below 0°C . Krastanow suggested that atmospheric ice crystals originate when these particles promote the freezing of already-formed droplets. Weickman subsequently discovered that ice crystals could be grown at high ice supersaturations only in very small numbers, whereas they appeared readily and plentifully on approach to water saturation. He concluded that ice nuclei first cause the condensation of vapour into liquid and then allow the liquid to freeze; he therefore called them "freezing-nuclei". Rau examined the freezing of supercooled droplets by atmospheric freezing nuclei and found that after several actions each became ineffective until the supercooling reached -33°C . Findeisen used a large cloud-chamber to investigate the effect of rate of expansion (corresponding to rate of ascent of damp air in the atmosphere) on the behaviour of ice nuclei, and discovered two classes of nuclei. Those of the first class were characterised by their rarity (1 or less per litre of air) and efficiency (acting at temperatures below about -7°C .), and were less effective the higher the rate of expansion; those of the second class were relatively very numerous, but produced crystals only below about -32°C ., and acted a little more readily the more rapid the expansion. Mr. Ludlam suggested that nuclei of the first class acted by allowing an adsorbed water film to freeze and thus produced an ice nucleus which grew by sublimation; and that with a high rate of expansion this ability was swamped when a consequent high supersaturation at the time of cloud formation involved the nucleus in droplet production, so that it then became a nucleus of the second class by causing the droplet to freeze when the temperature fell towards -33°C .

Mr. Ludlam then applied these results to the interpretation of cloud forms. In consequence of the time taken by ice particles to grow to an appreciable size and the short life of individual parts of cumulus, these clouds have to exceed the level at which ice particles originate by an amount depending upon their liquid-water content before they become transformed into cumulonimbus and the ice particles develop into precipitation. In very cold weather cumulus have very small liquid-water contents and do not produce showers until their summit temperatures have fallen to about -20°C . Mr. Ludlam also mentioned that the conditions inside cumulonimbus did not correspond to those assumed in the older theories of thunderstorm charge generation. He had been able to show that even at temperatures of -20°C . or -30°C . the larger precipitation elements were likely to have liquid skins, but that when the cloud tops reached above the -32°C . isotherm and the nuclei of the second class produced relatively large numbers of ice particles, these grow predominantly as wholly solid structures. Findeisen has given a new theory of charge generation which implies that the principal charging is associated with these solid structures, and Mr. Ludlam suggested that thunderstorms may occur only when the temperature of the cloud top falls below -32°C .

At temperatures between about -10°C . and -30°C . clouds usually contain both water and ice; at the higher temperatures the ice particles fall out and the water cloud survives, but at the lower temperatures the ice particles are more numerous and it is the droplets which disappear. At temperatures of about -40°C . ice clouds are rarely seen to possess mother-(water-)clouds, but are still to be regarded as a type of *fallstreifen*. Mr. Ludlam illustrated these points with some photographs.

M. Dessens of the Observatory of Puy de Dôme described how he had captured haze droplets upon fine spiders' threads and identified them with condensation nuclei. He hoped soon to be able to examine visually their behaviour at low temperatures.

Dr. Fournier d'Albe then described some experiments with a cloud chamber, which by employing smaller expansions more nearly imitated atmospheric processes than most apparatus of this kind. He found that in outdoor air ice crystals first appeared within the chamber-fogs when the temperature had fallen below $-32^{\circ}\text{C}.$, and that they then numbered not more than about 20 per cm^3 . At temperatures below $-41^{\circ}\text{C}.$ many more crystals appear, but only when the air is cooled to the dew point (not the frost point, even though no droplets may be detected). Artificial nuclei of sodium chloride produced droplets at temperatures above $-41^{\circ}\text{C}.$, but silver iodide provided true sublimation nuclei active at temperatures up to about $-7^{\circ}\text{C}.$ and at ice saturation.

Mr. Palmer emphasised that the nuclei important in rain production probably number less than 10 per litre and escape notice in an expansion chamber of ordinary size. He constructed in the Clarendon Laboratory a chamber in which about 5 litres of air could be examined for nuclei, and was then able to detect these rare nuclei and to show that their concentration varied from day to day. Using a smaller apparatus in an aircraft he had found that the ice nuclei acting at $-32^{\circ}\text{C}.$ at ground level were absent from the air above the lowest inversion or haze top.

Dr. Frith mentioned some unsolved problems, and remarked that although ice supersaturation in clear air might be expected to occur commonly, it had rarely been observed by the Meteorological Research Flight.

Dr. Dobson remarked that the latest results seem to indicate that the behaviour of ice nuclei varied with the duration of their exposure to changing conditions, and thanked all the speakers for contributing to such an interesting discussion.

ROYAL METEOROLOGICAL SOCIETY

Popular lectures

Some eminent meteorologists have very kindly consented to lecture on popular subjects expressly designed to interest amateur Fellows of the Society. These lectures will take place at monthly intervals throughout the coming session at the Science Museum Lecture Theatre, Exhibition Road, South Kensington. Visitors will be welcome.

The first lecture was given by Prof. Brunt, F.R.S., on November 10, on the subject "Where to live—a meteorological problem", and on December 3 there was an exhibition of a number of films designed to illustrate the wide scope of meteorology and the use of the ciné-film technique for instruction and research in this science.

Later arrangements will include the following lectures, each at 6 p.m.:—

January 12, 1949: SIR GEORGE SIMPSON, K.C.B., F.R.S.; Atmospheric electricity during the last 50 years—Sir Robert Watson Watt, F.R.S., in the Chair.

February 10, 1949: SIR NELSON JOHNSON, K.C.B., D.Sc.; Some international aspects of meteorology—Mr. E. Gold, F.R.S., in the Chair.

March 3, 1949: PROF. GORDON MANLEY, M.A., M.Sc.; British climatic fluctuations since Queen Elizabeth's day—Mr. Ian Kirkpatrick in the Chair.

April 6, 1949: DR. G. M. B. DOBSON, F.R.S.

May 5, 1949: MR. E. GOLD, C.B., D.S.O., F.R.S.

LETTERS TO THE EDITOR

Formation of rain

In the October 1948 issue of the *Meteorological Magazine* Mr. A. C. Best requests that reports of substantial rain associated with cloud tops below freezing level be forwarded to you. The following reports were compiled whilst I was Meteorological Officer in the Seychelles Islands, approximate position $4^{\circ}30'S$. $50^{\circ}E$. and are based on data supplied by the crews of a Catalina Ferry Flight operating from Mombasa to Seychelles.

Date	Time	Position	Cloud tops and precipitation
5.12.45	G.M.T. 0900–1100	$5^{\circ}S$. $50^{\circ}E$. to Seychelles	Aircraft flying at 10,000 ft., encountered cumulus bank, tops 8,000–12,000 ft. and descended to 1,000 ft., beneath the cloud, where heavy to moderate showers were encountered.
12.12.45	0900–1130	$5^{\circ}S$. $48^{\circ}E$. to Seychelles	Aircraft flew at 7,000 ft. and over cumulus cloud, tops 5,000–6,000 ft., and then descended below cloud where light to moderate showers were encountered.
2. 1.46	0500	$4^{\circ}30'S$. $41^{\circ}30'E$.	Aircraft when flying at 9,500 ft. encountered cumulus tops 7,000–8,000 ft. which, on descent, were found to be giving rise to moderate showers.
12. 1.46	0900–1100	$5^{\circ}S$. $51^{\circ}E$. to Seychelles	In this area 7–9 tenths cumulus cloud, base 1,200–1,500 ft., tops 7,000–10,000 ft., were giving rise to moderate to heavy showers, which at the Seychelles observing station were considered to be of sufficient importance to justify sending two deterioration reports to the mainland.

It should be noted that the terms “light”, “moderate” and “heavy” showers are used in the tropical sense of the word, and thus a moderate shower would mean a reduction in visibility from 20 miles to 1–2 miles in a very short space of time and in a heavy shower the visibility even on the ground is often reduced to half a mile.

In compiling the above data I have been very careful to exclude all cases when there was any medium cloud present or when there was any doubt as to the top of the cloud and nature of precipitation below the cloud. The period during which the reports were made was that of the NW. monsoon (NE. monsoon of India) and thus on many occasions both medium cloud and cumulonimbus were reported, and if such were the case then any reports of precipitating cloud with a top below freezing level have been ignored even if the cumulonimbus and medium cloud were far distant from the track of the aircraft.

The average temperature reported by aircraft when flying at 10,000 ft. was $11-12^{\circ}C$.

T. L. HUNT

Bawtry, November 2, 1948

The green(?) flash(?)*

All my life I have looked, as opportunity offered, for the so-called green flash; I had conspicuously failed to catch it. To-night, over the smooth water of the Red Sea, I have seen it.

I now know the main reason for my previous failures; my conception of what I was looking for was at fault. I had expected something green—and pictured emerald green; I had expected a flash, i.e. something momentary like lightning, whose duration was no more than that of the well known persistence of vision; and I had expected something extending perhaps 20' or 30' above and around the sunset point. It was none of these things.

The sun set in a rosy sky, so that the light-sensitive cells of my eyes were saturated with red light—a prerequisite to the observed complementary colour reaction. Just after the last trace of sun had disappeared—say within a second—a small irregularly defined patch of bluish-green light perhaps 6' long (one-fifth of the sun's diameter) and a minute or so high developed (that is the best word I can find for a non-instantaneous phenomenon) on the horizon around the sunset point, and, perhaps in another second, collapsed (this word does not suggest instantaneous extinction).

I was so taken by surprise at my success in seeing what had previously eluded me, that it was a second or two before I realised that this was the green flash; hence my description of dimensions and times may be somewhat imperfect. The biggest shock came from the fact that the colour was not emerald green, but could more fairly be described as bluish green; secondly, the smallness of the whole effect was contrary to my expectation. At the next opportunity, I shall know better what to look for.

The colour, dimensions and duration, being purely physiological, may easily vary with individuals, with the extent of the previous fatiguing of the red-sensitive cells, and with the sharpness of the actual sunset. This latter in turn could depend on the smoothness of the horizon, since a swell could allow lingering shafts of light to reach the eyes just as the mountainous edge of the moon gives rise to the "Baily's Beads" effect at a total solar eclipse.

L. J. COMRIE

R.M.S. Stratheden, Red Sea, June 25, 1948

NOTES AND NEWS

Special long-service awards

"A pleasant little ceremony took place in the Conference Room at Victory House on November 12, 1948, when the Director of the Meteorological Office, Sir Nelson Johnson, K.C.B., D.Sc., presented suitably inscribed barographs to two Merchant Navy captains in recognition of long and meritorious service as voluntary meteorological observers at sea. Capt. W. G. Higgs, O.B.E., Commodore of the Port Line Ltd., and Capt. R. P. Galer, C.B.E., R.D., R.N.R., of the Clan Line, were the recipients of these awards, and the ceremony was attended by the Marine Superintendents of the Port and Clan Lines respectively, and senior officers of the Meteorological Office.

*Reprinted, by permission, from the *Journal of the British Astronomical Association*.

Similar presentations were made, on behalf of the Director, by the Marine Superintendent, Commander C. E. N. Frankcom, to Capt. J. E. Wilson, O.B.E., Furness Line, aboard the *Nova Scotia* at Liverpool on October 12, 1948, and to Capt. W. H. Downing, Manchester Liners Ltd., aboard the *Manchester Progress* at Manchester on December 1, 1948.

Tornadoes in Ireland

Thanks are due to Miss C. M. Botley for pointing out, with reference to the tornado in Co. Kildare mentioned in the November 1948 number that an account of a tornado in Dublin in 1850 was published in the December 1929 number of the Magazine.*

Other records of Irish tornadoes have been received from Mr. F. E. Dixon of the Irish Meteorological Service, as follows:—

(a) September 4, 1767, at Santry near Dublin when a marquee with people in it was lifted in the air (*Dublin Journal*).

(b) October 5, 1851, at Limerick, roofs stripped of slates, boats lifted from the water, shattered windows blown outwards, large rafters found 200 yd. from a shattered roof, damage track less than 100 yd. wide.†

(c) Small one 15 yd. in diameter, August 16, 1941, near Camick-on-Suir when houses were unroofed and haycocks lifted.

Royal Geographical Society

Prof. C. G. Rossby will lecture at the Royal Geographical Society at 5 p.m. on Monday, January 24. His subject will be "Air-mass meteorology—its geographical implications".

OBITUARIES

John Dover, M.A.—It is with deep regret that we announce the death on November 7, 1948, of Mr. John Dover of Totland Bay. An appreciation of Mr. Dover's long association with the work of this Office was included in the July 1948 issue of this magazine.

Oswald Hawkins Latter who died on October 11, 1948, in his 85th year had been senior science master at Charterhouse from 1890 to 1926. On going to Charterhouse he set up a rain-gauge and other instruments in his garden and personally maintained these records up to the day of his death, a period of 58 years.

In addition to a keen interest in meteorology, Mr. Latter was regarded as an expert in biology. He made occasional contributions to *The Times* on the effects of weather on insect life.

REVIEW

The water resources of central Africa, by F. Debenham and *Climate and weather in modern naval warfare*, by Cdr. C. R. Burgess. *Geographical Journal*, London, **111**, 1948, pp. 222–234 and 235–250.

The September 1948 number of the Royal Geographical Society's *Geographical Journal* contains two articles of considerable interest to meteorologists.

*CORLESS, R.; An old weather diary and a tornado in Dublin in 1850. *Met. Mag.*, London, **64**, 1929, p. 266.

†GRIFFIN, D.; On the Limerick whirlwind of October 5th, 1851. *Proc. R. Irish Acad.*, Dublin, **5**, 1850–53, p. 225.

The origin of the fluctuations in level of the central African Lakes is a long-standing problem. Various theories have been propounded of which for a time correlation with the sun-spot cycle was the favourite. In his paper Professor Debenham gives a detailed explanation of the fluctuations of Lake Nyasa based on the growth of aquatic vegetation and the accumulation of silt in the outlet river.

Commander C. R. Burgess describes the work of the Naval Meteorological Service, Admiralty, on three important problems: (a) The extent of the doldrums belt and the weather in it, (b) the forecasting of sea and swell on beaches in relation to landing operations, and (c) forecasting the position of the edge of the Arctic ice sheet.

G. A. BULL

WEATHER OF NOVEMBER 1948

The month opened with pressure rather high over most of Europe and low to the north and west of the British Isles. A deep depression passed north-eastwards between Scotland and the Faeroes on the night of the 3rd and a much less deep centre south-eastwards across the mouth of the Channel on the 7th. High pressure then spread south-south-east from Greenland and an anticyclone was centred over the British Isles on the 8th. This system soon moved eastwards to the continent, where it remained nearly stationary for several days, while a large system of depressions advanced slowly towards the British Isles from the west. Eventually, on the 15th, a depression developed over Ireland and moved east-south-east across southern England, reaching Belgium on the 16th; it was followed by another which passed eastwards across northern Ireland and southern Scotland on the night of the 17th. Pressure had already begun to rise over central Europe on the 16th, and the anticyclone which soon developed persisted throughout the rest of the month. At one time (around the 22nd) its centre was over the British Isles. There were readings above 1040 mb. in Holland on the 24th and Germany on the 25th.

Mean pressure for the month was above 1025 mb. from the south-west of France across to Hungary and southern Germany, and below 1005 mb. over southern Greenland and the Atlantic to southward. Over most of North America it was between 1010 mb. and 1020 mb. It was above the average over the Mediterranean and practically all Europe south of the Arctic Circle, and above by as much as 10 mb. in north-east France, but was 5 to 10 mb. below normal in the Azores and over a large area of ocean north-west of the Azores. There was also an area with pressure 6 mb. below normal in the United States slightly to westward of the Great Lakes.

In the British Isles the weather of the month was dry on the whole and mild, particularly in the west and north. The week ending on the 20th was notably mild for the season. From the 22nd onward fog developed frequently, particularly in the eastern and Midland districts of England.

During the opening days Atlantic depressions moved north-east along our north-west seaboard, while associated fronts crossed the British Isles. Rain fell fairly generally and was heavy at times locally. Temperature fell appreciably on the 5th when a current of polar air flowed across the British Isles in the rear of one of the main depressions. On the 6th and 7th a shallow depression moved slowly from south-west of Ireland to France; considerable rain fell in southern England and south Ireland on the 6th. Meanwhile a wedge of

high pressure extending south from an anticyclone over Greenland gave mainly fair weather in northern districts of the British Isles. On the 8th an anticyclone over Scotland moved south-east and later turned east to central Europe and was associated with a spell of dry, rather cold weather over much of England. By the 11th a large complex depression over the Atlantic was beginning to affect our western districts and thereafter the air current over the British Isles was drawn from the south and a period of very mild weather ensued. On the 12th and 13th shallow secondaries moving north-east along our western seaboard caused rain in the west and north. On the 15th an elongated depression over Ireland moving east-south-east was associated with a gale in the south-west and rain in most parts, while on the 17th, an Atlantic depression moving rapidly north-east across the country caused further rain, heavy locally in the west. Among the largest falls of rain in 24 hours during this spell were 2·04 in. at Blaenau Festiniog and 2·30 in. at Cwm Dyli, Snowdon, on the 14th and 2·51 in. at Borrowdale on the 17th. On the 19th a very deep depression south of Iceland moved slowly north-east and an associated trough moved east-north-east over the British Isles; slight rain occurred in most places on the 19th and showers in the west and north on the 20th, while gale force was reached locally in the west and north.

In the rear of this depression an anticyclone developed to the north-west of the British Isles and subsequently moved south-east across the country to a position north of the Alps; there was practically no rain in Great Britain from the 22nd–25th. Widespread fog occurred in England (except the south-west) and locally in south Scotland. From the 26th–28th a trough of low pressure associated with a depression in mid Atlantic moved slowly east and gave slight rain in Ireland and west and north Scotland. Elsewhere mainly dry conditions continued, with widespread thick fog in many eastern and Midland districts of England and locally in south Scotland. At Kingsway, London, for example, persistent fog prevailed from 2100 on the 26th to the end of the month. In places with persistent fog it was cold, particularly during the 22nd–24th and 27th–30th, but at those places which escaped the fog mild weather and long periods of bright sunshine were enjoyed.

Rainfall somewhat exceeded the average in the extreme north-west of Scotland and the Shetland Islands in the neighbourhood of the Solway Firth, in the extreme south-west of Northern Ireland and in a coastal strip of Cardigan Bay. Less than half the average rainfall occurred in a large area in east Scotland, over most of north-east England and in the south-west tip of Cornwall.

The general character of the weather is shown by the following provisional values:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	67	18	+2·3	66	—4	108	25
Scotland ..	62	12	+2·8	81	—2	100	21
Northern Ireland ..	62	24	+4·0	81	—6	116	29

RAINFALL OF NOVEMBER 1948

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	1.76	75	<i>Glam.</i>	Cardiff, Penylan ..	2.45	60
<i>Kent</i>	Folkestone, Cherry Gdns.	2.49	77	<i>Pemb.</i>	St. Ann's Head ..	3.41	85
<i>"</i>	Edenbridge, Falconhurst	1.95	55	<i>Card.</i>	Aberystwyth ..	3.90	105
<i>Sussex</i>	Compton, Compton Ho.	2.05	54	<i>Radnor</i>	Bir. W. W., Tyrmynydd	3.67	55
<i>"</i>	Worthing, Beach Ho.Pk.	2.47	77	<i>Mont.</i>	Lake Vyrnwy ..	4.69	81
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	2.37	74	<i>Mer.</i>	Blaenau Festiniog ..	10.78	101
<i>"</i>	Bournemouth ..	1.61	47	<i>Carn.</i>	Llandudno ..	1.45	50
<i>"</i>	Sherborne St. John ..	1.73	61	<i>Angl.</i>	Llanerchymedd ..	3.29	78
<i>Herts.</i>	Royston, Therfield Rec.	1.53	66	<i>I. Man.</i>	Douglas, Boro' Cem. ..	3.81	81
<i>Bucks.</i>	Slough, Upton ..	1.85	83	<i>Wigtown</i>	Port William, Monreith	4.43	103
<i>Oxford</i>	Oxford, Radcliffe ..	1.50	65	<i>Dumf.</i>	Dumfries, Crichton R.I.	4.15	113
<i>N'hant.</i>	Wellingboro', Swanspool	1.49	69	<i>Roxb.</i>	Eskdalemuir Obsy. ..	5.30	91
<i>Essex</i>	Shoeburyness ..	1.67	78	<i>Peebles</i>	Kelso, Floors ..	1.82	79
<i>Suffolk</i>	Campsea Ashe, High Ho.	1.91	86	<i>Berwick</i>	Stobo Castle ..	2.47	75
<i>"</i>	Lowestoft Sec. School ..	1.48	63	<i>E. Loth.</i>	Marchmont House ..	1.87	62
<i>"</i>	Bury St. Ed., Westley H.	1.47	64	<i>Mid'l'n.</i>	North Berwick Res. ..	2.08	92
<i>Norfolk</i>	Sandringham Ho. Gdns.	1.38	56	<i>Lanark</i>	Edinburgh, Blackf'd. H.	2.33	104
<i>Wilts.</i>	Bishops Cannings ..	1.38	48	<i>Ayr</i>	Hamilton W. W., T'nhill	3.20	90
<i>Dorset</i>	Creech Grange ..	2.56	62	<i>"</i>	Colmonell, Knockdolian	2.75	55
<i>Devon</i>	Beaminster, East St. ..	2.34	59	<i>Bute</i>	Glen Afton, Ayr San ..	4.29	78
<i>"</i>	Teignmouth, Den Gdns.	1.76	55	<i>Argyll</i>	Rothsay, Ardenraig	4.69	93
<i>"</i>	Cullompton ..	2.29	67	<i>"</i>	L. Sunart, Glenborrodale	5.57	74
<i>"</i>	Barnstaple, N. Dev. Ath.	2.23	57	<i>"</i>	Poltalloch ..	4.08	72
<i>"</i>	Okehampton, Uplands	3.24	61	<i>"</i>	Inverary Castle ..	7.83	93
<i>Cornwall</i>	Bude School House ..	2.25	63	<i>"</i>	Islay, Eallabus ..	3.67	68
<i>"</i>	Penzance, Morrab Gdns.	2.11	46	<i>"</i>	Tiree ..	4.73	98
<i>"</i>	St. Austell, Trevarna ..	3.55	72	<i>Kinross</i>	Loch Leven Sluice ..	2.65	74
<i>"</i>	Scilly, Tresco Abbey ..	1.76	51	<i>Fife</i>	Leuchars Airfield ..	1.11	48
<i>Glos.</i>	Cirencester ..	1.75	59	<i>Perth</i>	Loch Dhu ..	6.69	77
<i>Salop.</i>	Church Stretton ..	1.87	60	<i>"</i>	Crieff, Strathearn Hyd.	3.10	71
<i>"</i>	Cheswardine Hall ..	2.12	82	<i>"</i>	Pitlochry, Fincastle ..	2.07	56
<i>Staffs.</i>	Leek, Wall Grange P.S.	2.02	65	<i>Angus</i>	Montrose, Sunnyside ..	1.03	39
<i>Worcs.</i>	Malvern, Free Library	1.47	58	<i>Aberd.</i>	Balmoral Castle Gdns. ..	.82	22
<i>Warwick</i>	Birmingham, Edgbaston	1.54	65	<i>"</i>	Dyce, Craibstone ..	1.08	33
<i>Leics.</i>	Thornton Reservoir ..	1.47	65	<i>"</i>	Fyvie Castle ..	1.44	42
<i>Lincs.</i>	Boston, Skirbeck ..	1.42	71	<i>Moray</i>	Gordon Castle ..	1.79	62
<i>"</i>	Skegness, Marine Gdns.	.83	38	<i>Nairn</i>	Nairn, Achareidh ..	1.74	77
<i>Notts.</i>	Mansfield, Carr Bank ..	.92	38	<i>Inv's</i>	Loch Ness, Foyers ..	4.93	126
<i>Ches.</i>	Bidston Observatory ..	..	..	<i>"</i>	Glenquoich ..	11.10	91
<i>Lancs.</i>	Manchester, Whit. Park	1.84	70	<i>"</i>	Fort William, Teviot ..	7.47	91
<i>"</i>	Stonyhurst College ..	3.64	81	<i>"</i>	Skye, Duntuiln ..	6.31	105
<i>"</i>	Blackpool ..	2.57	74	<i>R. & C.</i>	Ullapool ..	4.48	87
<i>Yorks.</i>	Wakefield, Clarence Pk.	.88	41	<i>"</i>	Applecross Gardens ..	7.00	108
<i>"</i>	Hull, Pearson Park ..	.74	34	<i>"</i>	Achnashellach ..	10.02	116
<i>"</i>	Felixkirk, Mt. St. John	.68	28	<i>"</i>	Stornoway Airfield ..	4.26	77
<i>"</i>	York Museum ..	.99	47	<i>Suth.</i>	Lairg ..	3.86	97
<i>"</i>	Scarborough ..	.69	28	<i>"</i>	Loch More, Achfary ..	9.03	106
<i>"</i>	Middlesbrough ..	1.34	63	<i>Caith.</i>	Wick Airfield ..	2.20	70
<i>"</i>	Baldersdale, Hury Res.	2.70	73	<i>Shet.</i>	Lerwick Observatory ..	4.39	103
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	1.28	54	<i>Ferm.</i>	Crom Castle ..	3.69	106
<i>"</i>	Bellingham, High Green	2.62	76	<i>Armagh</i>	Armagh Observatory ..	2.64	93
<i>"</i>	Lilburn Tower Gdns. ..	1.21	36	<i>Down</i>	Seaforde ..	2.02	53
<i>Cumb.</i>	Geltsdale ..	3.26	99	<i>Antrim</i>	Aldergrove Airfield ..	2.53	78
<i>"</i>	Keswick, High Hill ..	4.79	85	<i>"</i>	Ballymena, Harryville ..	3.00	74
<i>"</i>	Ravenglass, The Grove	4.47	100	<i>Lon.</i>	Garvagh, Moneydig ..	2.53	64
<i>Mon.</i>	Abergavenny Larchfield	1.90	50	<i>"</i>	Londonderry, Creggan	3.30	80
<i>Glam.</i>	Ystalyfera, Wern House	5.00	76	<i>Tyrons</i>	Omagh, Edenfel ..	3.71	98

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, JULY 1948

STATIONS	PRESSURE			TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE		
	Mean of day M.S.L.	Diff. from normal	Absolute		Mean values				Total			Diff. from normal	Days	Daily mean	Per- centage of possible	
			Max.	Min.	Max.	1 2	Min.	Diff. from normal								°F.
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.	hr.	%		
Gibraltar ..	1016.7	+0.8	93	47	60.6	62.3	55.0	-0.7	70	7.3	1.19	-0.98	9	5.8	36	
Malta ..	1016.8	0.0	92	63	81.2	74.3	67.5	-0.5	74	3.3	0.00	—	0	10.9	76	
St. Helena ..	1015.5	+0.8	89	61	81.7	74.1	66.5	-4.2	64	1.2	0.03	—	1	12.2	85	
Lungi, Sierra Leone..	1019.6	-0.5	66	53	61.3	58.0	54.7	-0.3	94	9.2	6.65	+2.52	28	—	—	
Lungi, Sierra Leone..	1013.9	—	87	69	81.3	77.1	72.9	—	90	8.5	27.15	—	29	—	—	
Lagos, Nigeria ..	1014.2	-1.0	87	65	82.8	76.1	69.4	-1.9	85	9.1	0.67	—	8	3.0	24	
Kaduna, Nigeria ..	1022.3	-0.6	82	51	75.3	66.1	57.0	+1.0	70	4.6	0.14	+0.01	2	5.9	52	
Chileka, Nyasaland ..	1020.4	-0.1	81	43	74.7	62.5	52.4	+1.0	63	1.6	0.00	-0.01	0	9.0	80	
Lusaka, Rhodesia ..	1022.9	-0.3	76	35	69.3	57.5	45.8	+0.8	62	2.9	0.02	-0.01	1	7.4	66	
Salisbury, Rhodesia..	1023.9	-1.3	76	33	62.1	54.3	46.6	-0.4	69	1.6	5.24	+1.62	21	—	—	
Cape Town ..	1003.9	+0.1	70	27	64.1	52.5	41.0	+2.4	88	8.5	0.14	-0.19	1	9.3	88	
Germiston, South Africa	999.0	-1.0	95	77	89.8	84.7	79.7	+1.0	87	8.6	11.16	-1.54	27	4.4	33	
Mauritius ..	1002.9	-1.0	91	73	86.1	82.3	78.4	+0.9	87	8.6	27.16	+2.89	19	1.5	11	
Calcutta, Alipore Obsv.	1003.5	-1.0	103	76	96.4	88.1	79.8	+0.5	68	8.3	3.35	-0.49	7	4.9	38	
Bombay ..	1008.7	-0.4	87	73	85.0	81.2	77.4	0.0	87	7.5	2.70	-1.73	16	6.1	49	
Madras ..	1008.5	-0.4	90	72	87.4	81.7	75.9	+0.4	81	7.9	11.49	+4.70	20	—	—	
Singapore ..	1019.7	+1.4	69	38	61.2	52.4	43.6	-0.3	62	3.0	0.77	-4.03	7	6.8	67	
Hongkong ..	1018.9	0.0	58	30	54.7	47.9	41.0	-0.8	77	6.0	0.58	-1.28	12	3.6	37	
Sydney, N.S.W. ..	1020.6	+0.4	70	37	57.6	51.1	44.6	-0.8	72	6.9	1.23	-1.41	14	3.2	32	
Melbourne ..	1017.8	-1.2	69	39	63.7	56.3	48.9	+1.1	71	7.0	8.65	+2.09	23	4.2	41	
Adelaide ..	1020.4	+0.5	71	31	60.9	51.3	41.6	+0.1	72	4.1	0.67	-0.20	7	—	—	
Perth, W. Australia..	1020.1	+1.7	74	37	68.7	58.2	47.7	-0.3	62	2.9	0.53	-1.67	7	8.3	78	
Coalgardie ..	1014.4	+0.7	59	32	51.7	45.5	39.4	-0.2	73	6.2	1.29	-0.89	16	4.3	46	
Brisbane ..	1014.9	+1.0	60	39	52.4	48.0	43.6	+1.6	86	8.1	7.41	+1.78	24	2.4	25	
Hobart, Tasmania ..	1014.5	+0.5	82	60	78.2	73.5	68.9	+0.1	77	6.7	3.17	-1.76	21	5.2	25	
Wellington, N.Z. ..	1011.9	+0.2	87	67	85.2	78.5	71.8	+0.3	79	5.8	2.96	-0.51	12	7.4	46	
Suva, Fiji ..	1014.4	-0.3	95	73	90.9	83.3	75.6	+1.6	69	4.3	2.23	+0.61	2	8.6	65	
Kingston, Jamaica ..	—	—	—	—	—	—	—	—	81	7.9	12.32	+2.89	29	—	—	
Grenada, W. Indies..	1013.8	-0.6	89	51	81.1	71.3	61.5	+2.2	75	5.5	1.31	-1.53	6	8.8	58	
Toronto ..	1010.3	-2.0	88	45	78.2	68.1	57.9	+1.7	86	6.1	4.06	+0.96	14	8.2	52	
Winnipeg ..	1011.7	-1.9	83	47	71.8	62.5	53.3	+2.1	85	6.5	4.09	+0.46	16	7.4	48	
St. John, N.B. ..	1016.4	-0.9	81	46	68.8	60.2	51.6	+0.1	89	5.5	1.40	+0.98	8	9.3	59	
Victoria, B.C. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	



Photograph by R.A.F.

THE TOP OF A SHEET OF ALTOCUMULUS
Looking east from 20,000 ft. in $51^{\circ}40'N$. $5^{\circ}45'E$.



Photograph by R.A.F.

CUMULUS AND HAZE
Looking south from 20,000 ft. in $53^{\circ}N$. $4^{\circ}E$. November 18, 1943.



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DUST DEVIL, HOUNSLOW HEATH, JULY 8, 1945

Two dust devils occurred during the Hamley Trophy Power Contest for model aircraft in 1945. This phenomenon was strong enough to lift a large petrol model (probable weight 4-5 lb.) several feet into the air.

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FREQUENCY OF WINDS BETWEEN GIVEN VELOCITIES

By C. E. P. BROOKS, I.S.O., D.Sc.

Windmills for generating electricity only operate between certain limits of wind speed. Below the lower limit the power generated is insufficient, above the upper limit the apparatus has to be put out of action to avoid damage. The frequency of winds within the effective range is therefore of great economic importance. Generators could well be mounted on towers about 100–200 ft. high, so that the range required is at this height.

The frequency distribution of winds in a normal circular distribution has been calculated by Brooks, Durst and Carruthers* in terms of “constancy” and resultant wind velocity. Constancy is defined as

$$100. \frac{\text{vector mean velocity}}{\text{scalar mean velocity}};$$

the tables can therefore be used for calculating the frequency distribution of winds of different velocities if we know the mean wind speed and the constancy. In the British Isles the constancy is about 40 per cent. near the surface and 50 per cent. in the free air.

An average effective range for a windmill is between 12.5 and 31.5 m.p.h. In Fig. 1 the smooth curve shows the calculated percentage frequencies of winds within this range (ordinate), for different mean wind speeds (abscissa), for a constancy of 40 per cent.

To see how this curve agreed with actual observations, mean wind speeds and frequencies between 12.5 and 31.5 m.p.h. were calculated by Dr. J. Glasspoole for 16 anemometer stations. The results are shown in Table I and by the small crosses on the left in Fig. 1.

The stations represent a great variety of exposures and some of them cover only a few years. Nevertheless, with the single exception of St. Ann’s Head, the observed and calculated values agree quite well. The discrepancy at St. Ann’s Head can be attributed to the exposure, which is very open on the

*BROOKS, C. E. P., DURST, C. S., and CARRUTHERS, N. ; Upper winds over the world. Part I, The frequency distribution of winds at a point in the free air. *Quart. J. R. met. Soc., London*, 72, 1946, p. 55.

TABLE I—OBSERVED AND CALCULATED FREQUENCIES OF WINDS, 12·5–31·5 M.P.H.

Station	Mean velocity	Frequency, 12·5–31·5 m.p.h.	
		Observed	Calculated
	m.p.h.	%	%
Bell Rock	18·0	59	62
Lerwick	17·5	58	60
St. Ann's Head	17·5	52	60
Scilly	17·2	57	58
Tiree	15·9	55	56
Kirkwall	14·6	53	53
Calshot	12·9	46	46
Cardington	12·5	35	44
Lympne	12·4	39	43
Gorleston	11·8	37	41
Croydon	11·0	31	35
Mildenhall	10·7	35	33
Birmingham	10·4	37	32
Cranwell	10·3	34	32
Aldergrove	10·0	29	30
Sealand	9·7	28	29

side of the strongest winds but sheltered on the side of the weaker winds, so that the frequency of the winds in the middle range tends to be too low. The reason why the other crosses with mean wind speeds of 17 m.p.h. or more lie slightly below the curve is probably that they are annual means ; the monthly mean

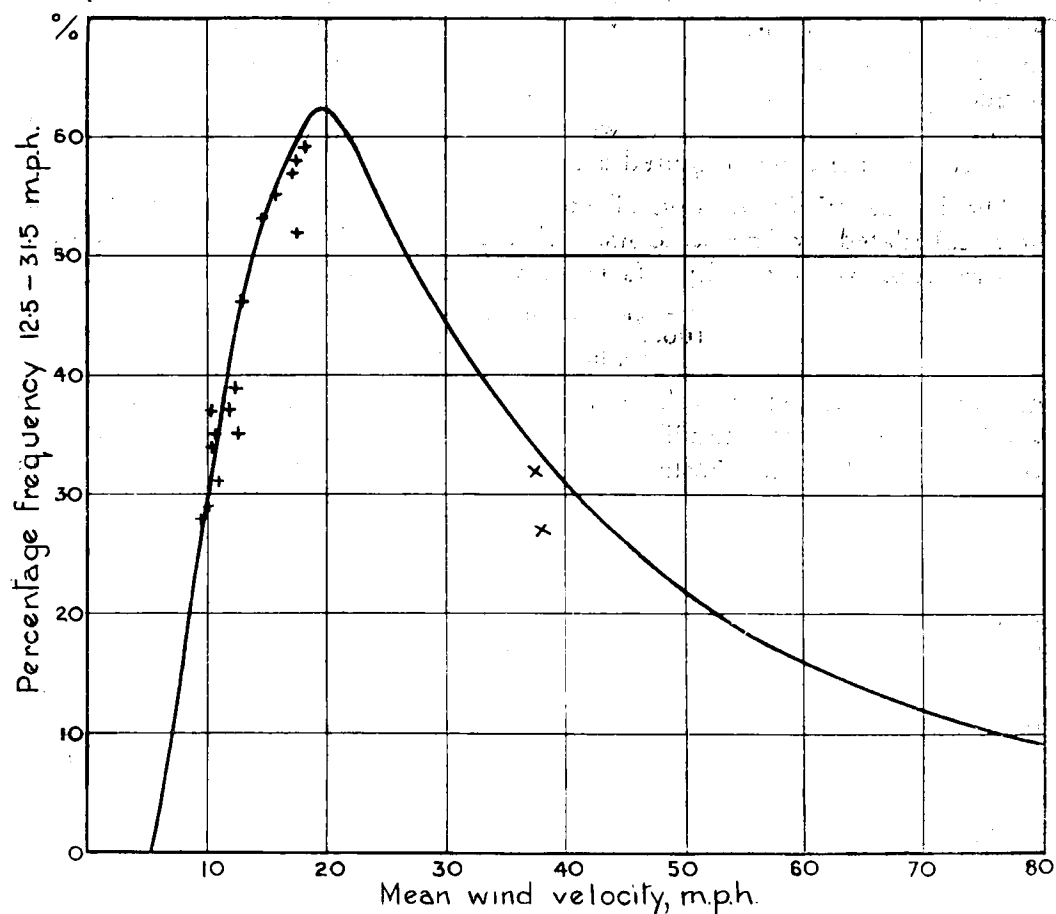


FIG. 1—DURATION OF WINDS BETWEEN 12·5 AND 31·5 M.P.H.

velocities are spread over a considerable range over which the curve is convex upwards.

These data, obtained in general at the normal anemometer height of 33 ft. above the ground, suffice to establish the ascending arm of the theoretical curve. Bell Rock with its effective height of 126 ft. has the highest mean wind velocity of any anemometer station in the British Isles and to check the descending arm of the curve it was necessary to use upper air data. For this purpose the observed frequencies at Larkhill, December-February 1939-40 to 1944-45 at the 600-mb. level and at Lerwick, June-August 1942-44 at the 400-mb. level, extracted from "Upper winds over the world", were used ; these gave :

Larkhill, mean velocity 38 m.p.h., frequency, observed 27 per cent., calculated 32 per cent.

Lerwick, mean velocity 37.5 m.p.h. frequency, observed 32 per cent., calculated 33 per cent. Here again the agreement is as good as could be expected.

From Fig. 1 it appears that the greatest duration of winds between 12.5 and 31.5 m.p.h. in the British Isles is found where the mean wind is between 15 and 25 m.p.h. But the frequency distribution of winds within this range varies according to the mean wind velocity. The higher the mean velocity the greater the proportion in the upper half of the range. Fig. 2 shows the distribution of effective energy, obtained by multiplying the frequency by the cube of the wind velocity. The abscissa is the mean wind velocity as before ; the ordinate is the effective energy expressed as a percentage of the maximum possible, which would be given by a steady wind of 31.5 m.p.h. blowing all the time. The maximum energy is given by a mean wind velocity of about 23 m.p.h.

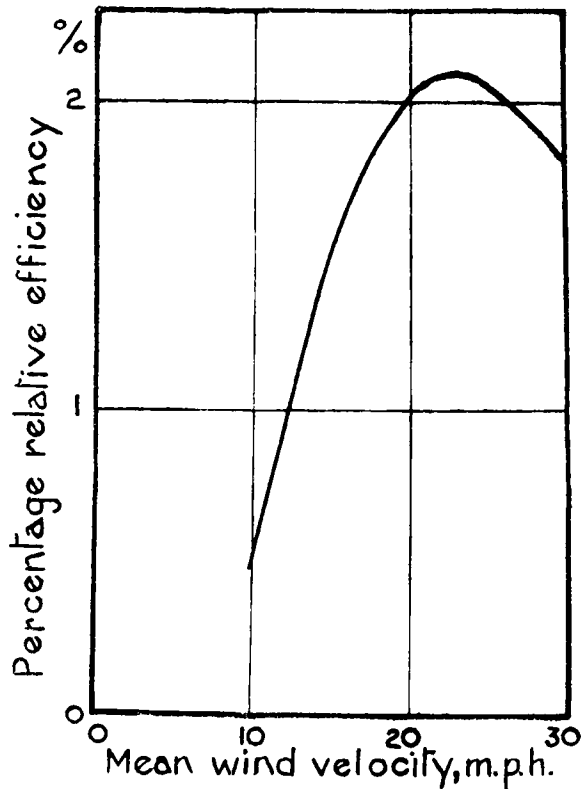


FIG. 2.—RELATIVE EFFICIENCY OF WINDS

At a height of 33 ft. the highest mean velocity in the British Isles is about 17.5 m.p.h. At a height of 200 ft. the mean velocity is about 1.35 times that at 33 ft.,* so that at 200 ft. the greatest mean velocity to be expected is about 24 m.p.h., which comes near the point of greatest efficiency. In such conditions, allowing for the annual variation of mean velocity, the realisable power would be about two per cent. of the theoretical maximum.

ESTIMATION OF TEMPERATURE IN THE 700-MB. AND 500-MB. SURFACES

By J. M. CRADDOCK, M.A.

The present investigation was undertaken to provide the practical upper air analyst with a tool capable of routine use over the wide area in temperate latitudes for which upper air information is regularly available. The general nature of the results is not unexpected, and could indeed be deduced from a paper published by Mr. C. K. M. Douglas in 1930.†

A frequency table was constructed, the elements being t , the thickness of the 700–500-mb. layer, and T_7 , the temperature at 700 mb., as given by each available upper air sounding on each of 12 days (one day being chosen at random from each month of the year 1947). The area covered was that of the main upper air charts at the Central Forecasting Office, and the data were obtained from the filed tephigrams. The soundings relate to conditions of extreme heat, in the north African summer, and of extreme cold, in Russia and Greenland in winter, as well as to maritime and continental air masses of the types usually affecting the British Isles. The filed tephigrams included a few soundings which had been rejected on grounds of instrumental or transmission errors; these were ignored, and the rest, 1,071 in all, are grouped in a frequency table (Table I), the grouping interval being 50 ft. for the thickness of the 700–500-mb. layer and 2°F. for the 700-mb. temperature.

A second frequency table was made, the elements being t , the 700–500-mb. thickness, and T_5 the temperature at 500 mb. plotted for all stations on the main upper air charts at the Central Forecasting Office on each of 12 days. As before, the days chosen were intended to include the full range of temperature to be expected during the year while minimising the likelihood that any one type of pressure field was unduly prevalent, but subject to this the charts taken were those which came readily to hand. The days examined were the 6th and 7th of the following months: January 1946, January 1947, and February to May 1948. A few observations were rejected which had been disallowed in the analysis, and where there was some additional reason to doubt their correctness. Neglecting these, fewer than 20 in all, 1,286 observations remained, and were grouped in a frequency table (Table II), the grouping intervals being the same as for the first table.

From Table I the correlation between T_7 in degrees Fahrenheit and t in feet is found to be .974, the regression of 700-mb. temperature on thickness is

$$T_7 = .0537t - 429, \quad \dots (1)$$

the standard deviation of the coefficient of t is .00048, and the standard deviation of T_7 for given t is 3.28°F.

*CARRUTHERS, N.; Variations in wind velocity near the ground. *Quart. J. R. met. Soc., London*, 69, 1943, p. 289.

†DOUGLAS, C. K. M.; On the relation between temperature and pressure in the troposphere. *Mem. R. met. Soc., London*, 3, No. 29, 1930, p. 159.

TABLE I—FREQUENCY OF TEMPERATURES AT 700 MB. FOR DIFFERENT 700-500-MB. THICKNESSES

Thickness of 700-500-mb. layer in feet

[illegible]

TABLE II. FREQUENCY OF TEMPERATURE AT 500 MB. FOR DIFFERENT 700-500-MB. THICKNESSES

°F.	Thickness of 700-500-mb. layer in feet
15, 16	8,710-
13, 14	8,700-
11, 12	8,650-
9, 10	8,610-
7, 8	8,550-
5, 6	8,510-
3, 4	8,450-
1, 2	8,410-
0	8,360-
-1, 0	8,310-
-3, -2	8,250-
-5, -4	8,210-
-7, -6	8,160-
-9, -8	8,110-
-11, -10	8,100-
-13, -12	8,050-
-15, -14	8,010-
-17, -16	7,960-
-19, -18	7,910-
-21, -20	7,860-
-23, -22	7,810-
-25, -24	7,760-
-27, -26	7,710-
-29, -28	7,660-
-31, -30	7,610-
-33, -32	7,560-
-35, -34	7,510-
-37, -36	7,460-
-39, -38	7,410-
-41, -40	7,360-
-43, -42	7,310-
-45, -44	7,260-
-47, -46	7,210-

The regression of thickness on 700-mb. temperature is given by the same table as

$$t = 17.65T_7 + 8009, \quad \dots (2)$$

the standard deviation of the coefficient of T_7 as .1262, and the standard deviation of t for given T_7 as 58.5 ft.

From Table II the correlation between T_5 in degrees Fahrenheit and t in feet is found to be .962, the regression of 500-mb. temperature on thickness is

$$T_5 = .0520t - 446, \quad \dots (3)$$

the standard deviation of the coefficient of t is .00042, and the standard deviation of T_5 for given t is 3.17°F.

The regression of thickness on 500-mb. temperature is given by this table as

$$t = 17.81T_5 + 8557, \quad (4)$$

the standard deviation of the coefficient of T_5 as .1406, and the standard deviation of t for given T_5 as 68.70 ft.

Subtracting (3) from (1), we have

$$T_7 - T_5 = .0017t + 17 \quad \dots (5)$$

The coefficient of t is significantly greater than zero, so that there is reason to think that the difference, $T_7 - T_5$, tends to be greater at high temperatures than at low.

Using equations (1) and (3), graphs may be drawn to give the most probable 700-mb. and 500-mb. temperatures corresponding to any given thickness, while equations (2) and (4) can be used for the reverse process. In practice, however, the differences between equations (1) and (2) and between (3) and (4), which arise through the two correlations falling short of unity, are small enough (less than 1°F. over the normal range of temperatures) to be disregarded in the interests of convenience. Accordingly a graph has been constructed (Fig. 1), based on the tephigram, which is a compromise and can be used to obtain temperatures from thicknesses or thicknesses from temperatures as the occasion may demand. The uses of this graph are described in the following

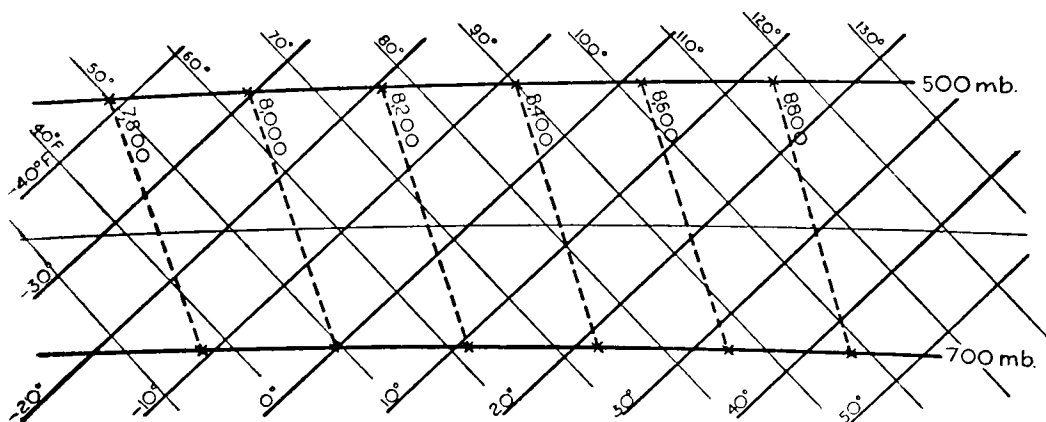


FIG. 1—RELATION BETWEEN 700-500-MB. THICKNESS AND TEMPERATURES AT 700 AND 500 MB.

Full lines give temperatures at 700 and 500 mb. in degrees Fahrenheit, pecked lines give thicknesses in feet

sections. It is especially convenient for use at a station where the technique of upper air analysis in use at the Central Forecasting Office is employed, because in that technique the isopleths of thickness of the 700–500-mb. layer are drawn as an integral part of each actual and prognostic chart, and are studied more closely and forecast more accurately than is possible for the isotherms in a particular surface.

The graph gives directly the temperature at 700 and 500 mb. corresponding to any given thickness. The temperatures corresponding to the isopleths of thickness used in the analysis at the Central Forecasting Office (those for multiples of 200 ft.) are not in general multiples of 10°F. , for which isotherms are drawn, so that the isotherms usually lie between but follow the run of the thickness lines. The equivalence given by the graph (or more exactly by equations (1) and (3)) is, of course, appropriate only in places where there is no other information as to the probable lapse rate. If an air mass shows evidence of subsidence, or of deep instability, so that the lapse rate may be expected to differ from the mean, an allowance should be made by drawing the isotherms to some extent across the run of the thickness lines. Since, however, the magnitude of the standard deviations for given t of T_7 and T_5 show that fewer than 1 in 20 measured temperatures differ from the mean value by as much as 7°F. , the allowance for stability or instability should be less than this unless the analyst considers that the situation in question is a wholly abnormal one. The analyst will, of course, take account of all actual reports in drawing the isotherms and estimating stability on a current chart, and, when forecasting, will consider how far the stability of any air mass as shown on the latest analysed chart is likely to change.

If the temperature at 700 or 500 mb. is accurately known, *e.g.* from the report of a meteorological reconnaissance aircraft, then the 700–500-mb. thickness will, on fewer than 1 in 20 occasions, differ from the value given by equation (2) or (4) by as much as 117 ft. or 137 ft. respectively. While such an estimate is considerably less accurate than one based on a good upper air sounding, it will serve to confirm or deny a doubtful sounding, and is quite accurate enough to be valuable in regions where no proper upper air soundings are available.

The 700–500-mb. thickness and the 500-mb. temperature are plotted on the same upper air chart at the Central Forecasting Office, and equation (3) gives a convenient check of the internal consistency of the observations. If a reported temperature does not differ from that derived from the thickness by as much as 7°F. , there is no reason to suspect internal inconsistency. If the difference exceeds this figure, the incoming message should be examined with a view to eliminating transmission and clerical errors from the plotted observation. At the same time, since the frequency table shows not that larger differences are impossible but that they are rare, it is inadvisable to reject an observation which is otherwise satisfactory simply because the difference lies somewhat outside the usual range.

ERRATUM

January 1949, PAGE 21, line 5; *for* at 450 mb. in winter is 50°F. between 51°N. and 57°N. *read* at 450 mb. in winter is 50°F. between 38°N. and 67°N. , and 42°F. between 51°N. and 57°N.

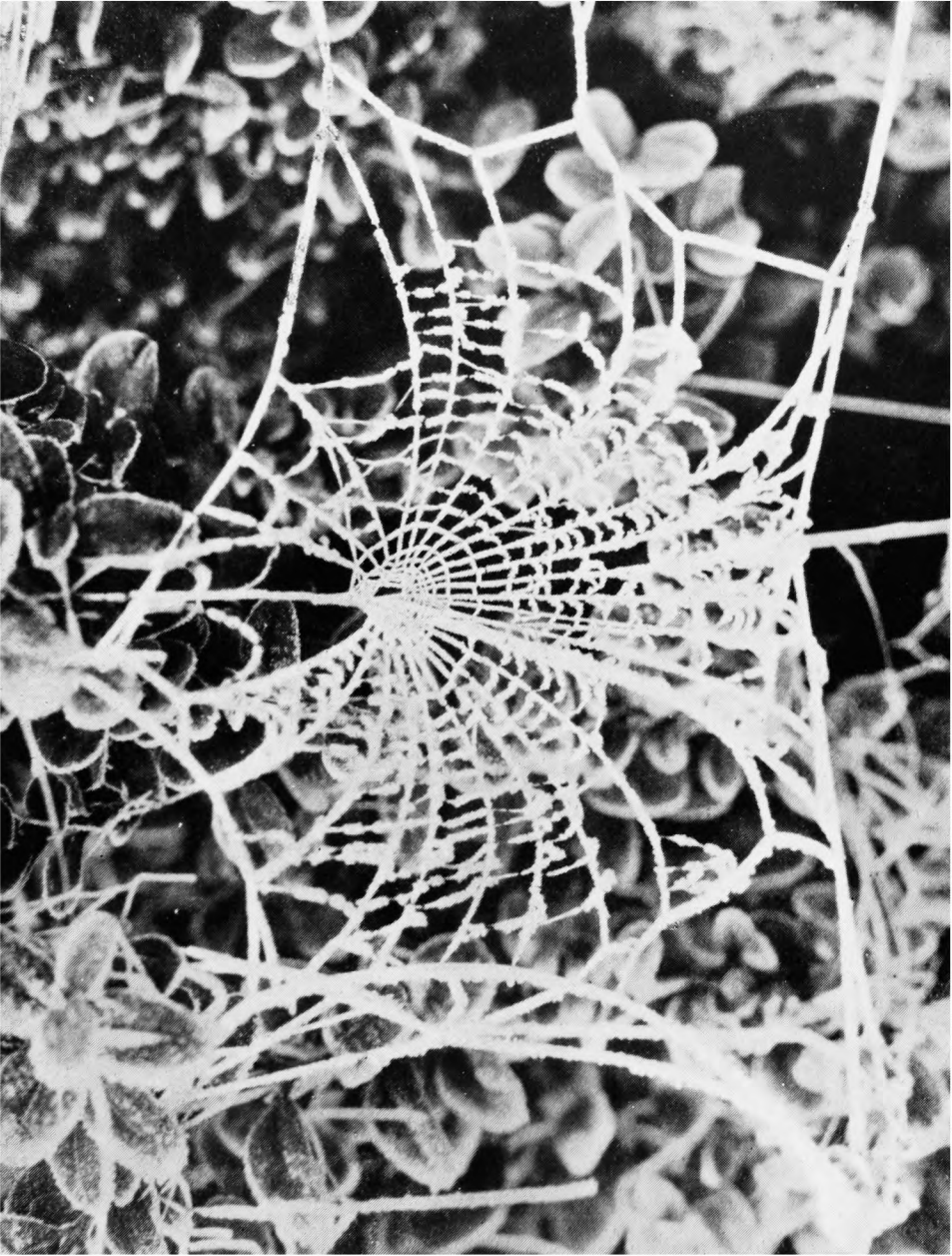


FIG. 1—RIME ON A COBWEB AT LEEMING, NOVEMBER 23, 1948
(see p. 53)



FIG. 3—CLOSE-UP OF RIME AT LEEMING
(about three-quarters natural size)

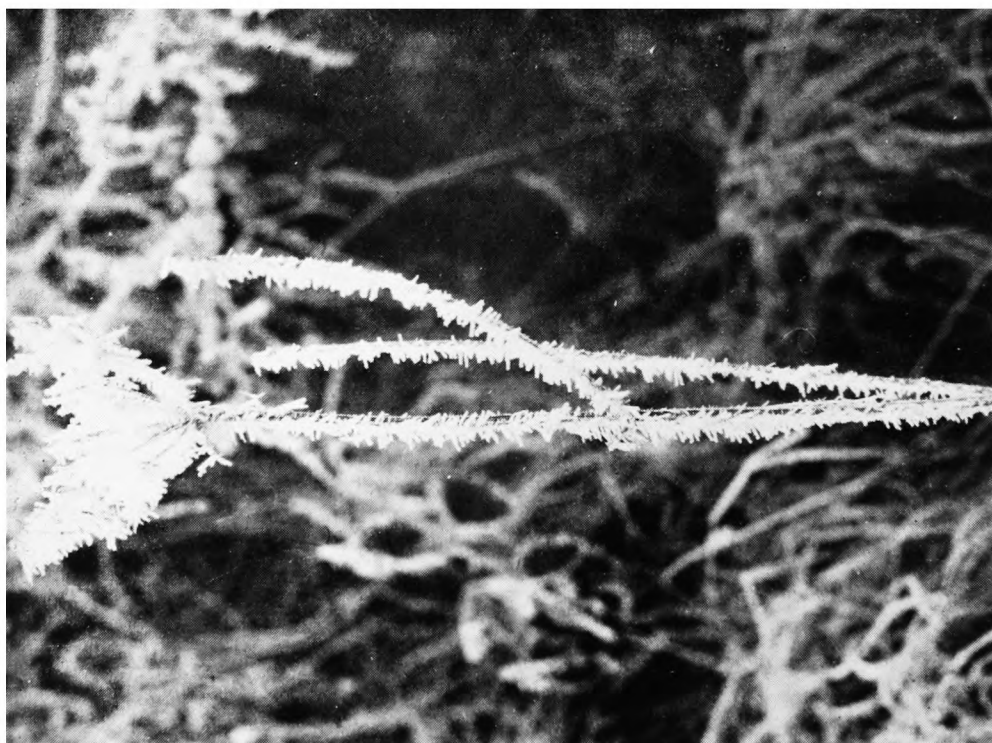


FIG. 2—RIME ON SHRUB AT LEEMING .
(see p. 53)

UNUSUAL WARM-FRONT PASSAGE AT LEUCHARS, FIFE,
NOVEMBER 20, 1947

BY T. JOHNSTON

The following note gives a picture of the unusual passage of a warm front through the Leuchars area with a suggested reason for the peculiarities noted. No attempt is made to go deeply into the mechanism behind the suggestion.

On the 20th at 0600 G.M.T. a warm front lay from just south of Benbecula to Renfrew to Silloth to Croydon to north-east France. Behind it lay a wide warm sector in which the air had a long south-westerly track and was, for the season, very warm. The depression centre lay well to the west, the main centre being at 52°N. 33°W., and it was expected that by 1200 G.M.T. the front would lie from the Hebrides to Aberdeen to the western North Sea, having passed through Leuchars at about 0900 G.M.T. Local forecasts for the Leuchars area were prepared accordingly.

The weather in eastern Scotland during the preceding five days had been very cold and frost had been recorded every morning. The minimum air temperatures at Leuchars on the 18th and 19th were 22°F. and 21°F. It became cloudy on the evening of the 19th, light drizzle commenced at 2300 and the temperature rose gradually through the night to 39°F. at 0600. Thereafter the hourly sequence of local weather at the station is shown in detail in Table I.

TABLE I—WEATHER AT LEUCHARS, NOVEMBER 20, 1947

Time G.M.T.	Weather	Visibility	Cloud		Wind	Temperature	
						Dry bulb	Wet bulb
		yd.	tenths	ft.		°F.	°F.
0700	Continuous slight drizzle	3,000	10	1,200	Calm	39	39
0800	Continuous slight drizzle	1,400	10	1,000	Calm	39	39
0900	Continuous slight drizzle	1,800	10	800	SW., 2kt.	38	38
1000	Continuous slight drizzle	1,800	10	800	Calm	39	39
1100	Continuous moderate drizzle	1,500	10	800	Calm	39	39
1200	Slight drizzle and fog	600	10	600	Calm	39	39
1300	Slight drizzle and fog	600	10	600	Calm	39	39
		mi.					
1400	Cloudy	10	{ 5 8	3,000 700	SW., 12kt.	54	54

It will be seen that there was no rise in temperature until after 1300. When this did occur, at 1330 G.M.T., the wind rose suddenly to WSW., 12 kt. and the temperature, in ten minutes, rose from 39°F. to 52°F. The visibility also rose from fog limits to 10 miles in an equally short space of time. The rapid rise in temperature is graphically shown by the reproduction of the thermograph trace, Fig. 1. It would appear that the warm front passed through Leuchars at 1330, having been preceded by conditions usually encountered when the frontal surface at ground level has been retarded by a shallow friction layer, *i.e.*, by pre-frontal fog. But the front passed through Dyce before 1300 G.M.T., as will be seen from Fig. 2, which shows the synoptic chart for Scotland at that hour. For comparative purposes Table II shows the temperatures at Leuchars, Donibristle and Dyce during the morning.

It will be seen that there was a marked rise of temperature at Donibristle between 0900 and 1000 followed by a continuing rise, and at Dyce between 1100 and 1200. It is therefore reasonable to expect that at Leuchars the

TABLE II—TEMPERATURE AT DONIBRISTLE, LEUCHARS AND DYCE, NOVEMBER 20, 1947

Time	Donibristle		Leuchars		Dyce	
	Dry bulb	Dew point	Dry bulb	Dew point	Dry bulb	Dew point
G.M.T.	<i>degrees Fahrenheit</i>					
0700	44	43	39	39	41	39
0800	43	43	39	39	41	40
0900	42	42	38	38	42	40
1000	47	46	39	39	42	40
1100	51	50	39	39	42	39
1200	58	53	39	39	50	45
1300	59	54	39	39	51	47

temperature rise would have occurred somewhere between 0900 and 1100. The frontal passage everywhere had been particularly marked by temperature changes and it would appear, therefore, that the warm front did not then pass through Leuchars, on the surface, until after it had passed through Dyce, 70 miles to the north. At Arbroath no observations were taken after midday, but it is understood that the thermographic records there showed a marked and sudden rise of temperature at 1330 G.M.T. This would suggest that the phenomenon was not confined completely to Leuchars.

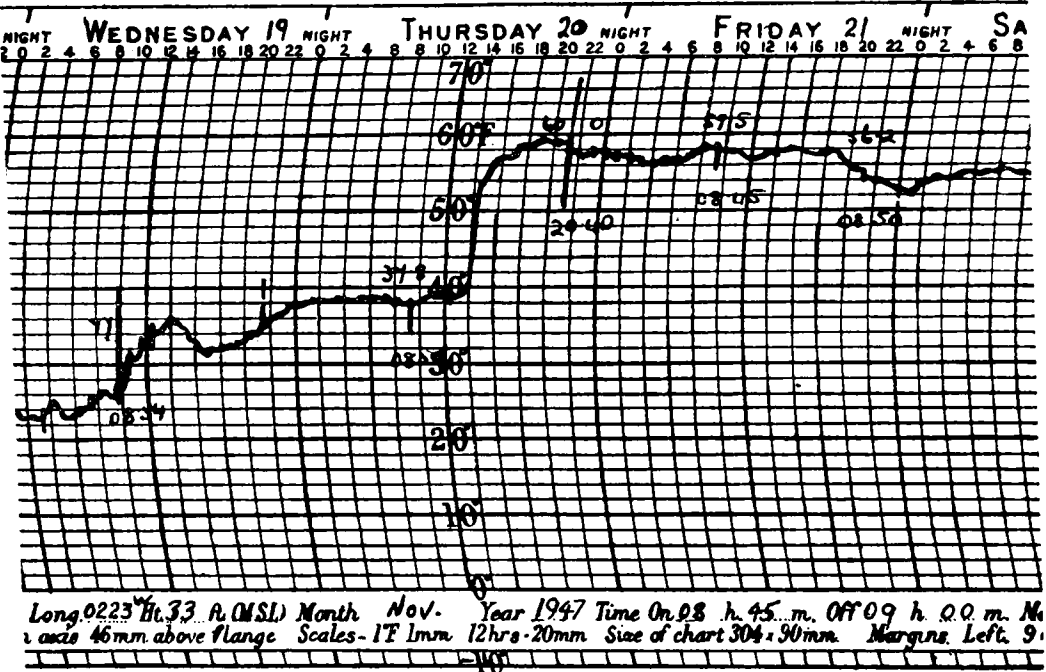


FIG. 1—THERMOGRAM AT LEUCHARS NOVEMBER 19-21, 1947 .

No upper air soundings of temperature were made at Leuchars during the period under review but radio winds are available and are shown in Table III.

TABLE III—UPPER WINDS AT LEUCHARS

Height	0500		1100	
ft.	°	kt.	°	kt.
Surface	Calm		Calm	
1,000	220	24	230	24
2,000	240	25	230	30
3,000	260	33	240	45

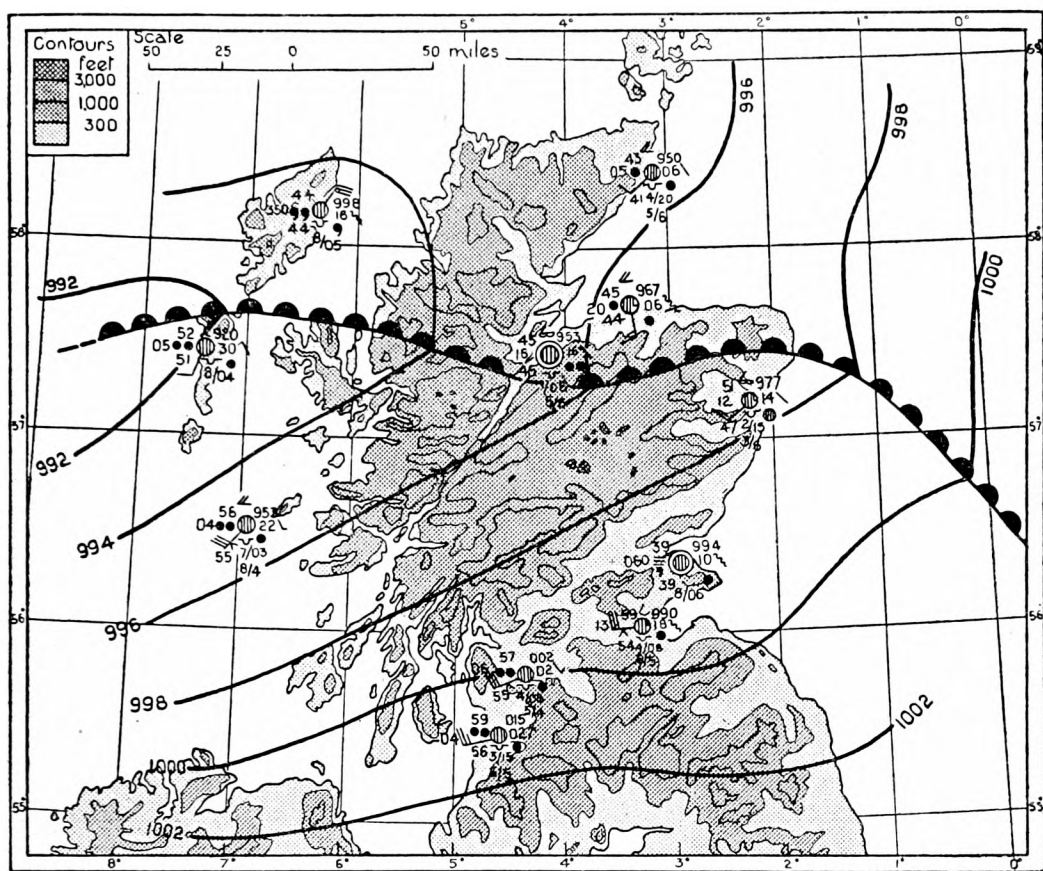


FIG. 2—SYNOPTIC CHART, 1300 G.M.T., NOVEMBER 20, 1947

Such marked variation between the wind at 1,000 ft. and the surface value in a south-westerly air stream is very unusual although there is certain shelter from the hills to the south-west of the area.

It is suggested that during the five days before the 20th a cold pool of air formed in the natural basin bounded on the north-western side by the Sidlaws and on the south-western and southern sides by the Ochils, Lomonds and higher ground of south Fife (see Fig. 3). When the warm air approaching from the south-west was lifted over this latter high ground it flowed over the top of the pool of cold air and reached the surface at a point north of Arbroath. The warm air then eventually reached the surface in the basin, not through violent and deep turbulence, which would have given a less sudden rise in temperature but through a process of gradual and comparatively shallow mixing with the top of the cold pool. Mr. C. K. M. Douglas has suggested that if the anemometer trace at Bell Rock—the only recording anemometer in the area—showed a complete calm just before the rise in the temperature it would prove mixing up to the level of the head at least. Unfortunately this suggestion could not be pursued as there is no record of the time that the temperature rose at Bell Rock, and, although it occurred sometime after the 1200 G.M.T. observation which might signify that the cold pool extended as far east as that, there is no more evidence to support this possibility.

If this theory is accepted, then, from a purist point of view, it would doubtless be correct to draw the warm front on the surface charts south of this basin in

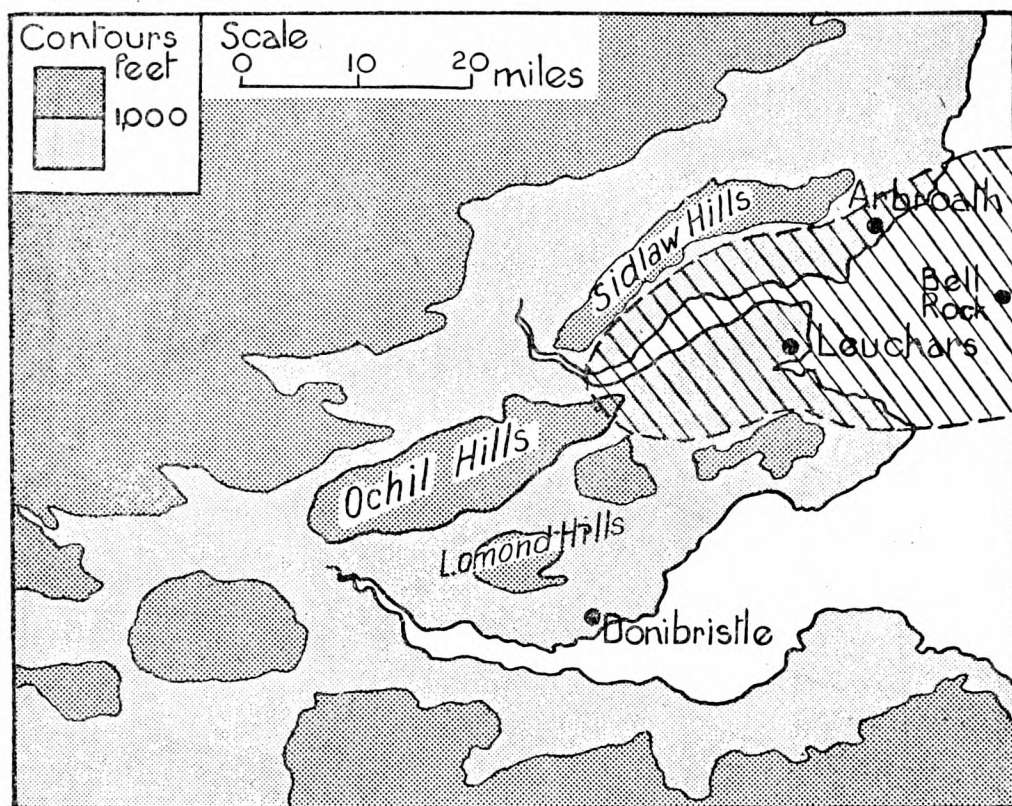


FIG. 3—SUGGESTED AREA OF COLD POOL (SHADED AREA)

the form of a wave but if this were done, for example at 1300 G.M.T. when the front would have to be through Aberdeen, the picture would be rather a peculiar one. It is not known whether such marked effects have been noticed before at this station, but it seems unlikely that they would be numerous as it must be comparatively rare to have such a marked difference in air temperatures in air masses in juxtaposition.

It might be mentioned in passing that the sudden rise of temperature had the effect of causing very rapid and severe condensation on walls and other surfaces indoors, and rivulets of water coursing down walls were not unusual.

Acknowledgements are due to Messrs. C. K. M. Douglas, D. A. Davies and T. N. S. Harrower who read the original draft of this note and made helpful suggestions.

METEOROLOGICAL RESEARCH COMMITTEE

The 56th meeting of the Committee was held on December 9, 1948.

The Committee discussed the working of the three Sub-Committees formed earlier in the year and agreed that the procedure of dealing with most of the technical papers in Sub-Committees had proved successful. It was agreed to invite some additional "outside" scientists to join the Sub-Committees.

The Committee also heard an interesting account of an attempt, which is being sponsored by the Director, Naval Meteorological Service, to compile synoptic charts of the oceans surrounding the South Pole.

OFFICIAL PUBLICATIONS

The following publications have recently been issued :—

HANDBOOK OF WEATHER MESSAGES, CODES AND SPECIFICATIONS, PARTS II AND III.

This publication, which replaces “Wireless weather messages”, consists of three parts : Part I, containing the transmission schedules of all weather broadcasts under direct British control, a list of all British synoptic reporting stations and a selection of other reporting stations ; Part II, containing full specifications of all the weather codes in use in Europe as amended since the war ; and Part III, containing instructions for coding, decoding and plotting. These three Parts, together with the amendments, contain all the new Washington codes which are now in use in Europe. An article on the Washington codes appeared in the October 1948 issue of the *Meteorological Magazine*.

Part I will be issued shortly.

PROFESSIONAL NOTES

No. 92—*Persistence of Weather*, by E. G. Bilham, B.Sc., D.I.C.

Common experience in this country shows that on most occasions the weather an hour ahead will not be materially different from what it is now. But no exact figures have been available as to the actual frequency of change, or of the material change from one hour to the next. Professional Note No. 92 gives the first results of an inquiry for two stations wide apart: Croydon and Leuchars. Broadly the figures show:—

(1) Only in 1 case out of 5 are the conditions an hour hence exactly the same as they are now.

(2) In 7 cases out of 10, the changes are slight and not of material significance from the flying point of view.

(3) In 1 case in 6 there are material changes in an hour—half the changes being improvements and half deteriorations.

(4) In 9 cases out of 10 the conditions an hour hence will be either about the same or better than they are now.

There are annual and diurnal variations—but the latter have not yet been examined. The annual variation shows, as might perhaps be expected, that winter is the season of most frequent material change.

It is hoped to provide similar summaries for other stations in further notes, and also to consider changes in a period of three hours in addition to those in a period of one hour.

No. 93. *Preliminary note on errors in forecast frontal positions on 18-hour prebaratics*, by C. K. M. Douglas, B.A.

The paper discusses the errors in forecasts of the positions of fronts 18 hours in advance. It was written in 1944, but an addendum gives statistics for the years 1944 to 1946 which do not differ appreciably from those for 1944 only. The average error in the forecast positions of fronts (warm, cold and occluded taken together) is 85 miles, corresponding to an error in the speed of just under 5 m.p.h. Various sources of error are discussed. The most important of these is the difficulty of making a sufficiently accurate forecast of the pressure distribution, but the ageostrophic motion of fronts is also considered.

No. 94—*Visibility and the optical properties of the atmosphere*, by Sir George Simpson, K.C.B., F.R.S.

This is a reprint of two memoranda prepared by Sir George Simpson during the war for the information of the Civil Defence Research Committee setting out the principles on which the Meteorological Office bases its observations of visibility. The physics of visibility and the results of Koschmieder's investigations are described. The theoretical relationships between the attenuation coefficient, the daylight visibility range and the distance at which lights can be seen at night are derived, and the practical difficulties of applying the theory are discussed.

A useful diagram is reproduced by which values of the visible range, the attenuation coefficient and the transmission coefficient expressed in either the mile, the kilometre or 1,000 yards as the unit of length can be converted into the corresponding values for either of the other units.

No. 95—*Calculation of night minimum temperatures*, by R. Frost, B.A.

In this note it is assumed that the temperature changes near the surface of the earth depend mainly upon the readiness with which the loss of heat from the surface is compensated by the transfer of heat downwards from the air and by the heat released by the deposition of dew.

Starting with the eddy-diffusion equation

$$\frac{\partial \chi}{\partial t} = \frac{\partial}{\partial z} \left(K_z \frac{\partial \chi}{\partial z} \right),$$

where χ is either the potential temperature or humidity mixing ratio of the air and K_z , the coefficient of eddy diffusion, is represented by a power law of the height above the surface, a solution is obtained on the assumption that, to a first approximation, the radiational flow of heat from the earth's surface and the rate of deposition of dew during the night may be taken as constant.

It is shewn that when the ground is dry the fall of temperature calculated from this solution is in close agreement with the observed fall.

ROYAL SOCIETY

At the meeting of the Royal Society on November 11, two meteorological papers were read :—

Chapman, S. and Tschu, K. K.—The lunar atmospheric tide at 27 stations widely distributed over the globe.

Goody, R. M.—The thermal equilibrium at the tropopause and the temperature of the lower stratosphere.

During the past 120 years, many investigators have attempted to show the existence of a lunar tide in the atmosphere. From data of barometric pressure at tropical stations this is comparatively simple, but with similar data for temperate regions the determination is much more difficult. It was Prof. Chapman who, in 1918 by an analysis of the pressure on quiet days selected from 63 years' data at Greenwich, first showed the existence of the lunar tide at a station in temperate latitudes. Since then he has contributed to the subject of lunar oscillations not less than twenty papers. Much of the substance of

these is given in an article in *Nature**. At the meeting now reported, many interesting slides were shown. One of the most striking was that of a harmonic dial giving the amplitude and phase of the lunar tide at Taihoku (Formosa) for the different months of the year (data for 1897 to 1932). This showed very clearly the large phase lag in January and February ; a feature which has been found to be world-wide irrespective of hemisphere. From December to February the crest of the atmospheric tide (at Taihoku) occurred between two and three hours after lunar transit whereas for the remaining nine months the lag was approximately one hour only.

The magnitude of the lunar tide over the world, for the year as a whole, was shown by isopleths of amplitude. These brought out clearly the maximum of about 80 microbars† over the Indian Ocean and the damping, due to the Rockies, along the west coast of North America.

A semi-diurnal lunar oscillation had been found also in data of temperature and wind and in the height of the E-layer of the ionosphere. The magnitude (given by the range from peak to trough) was of the order of 0.01°C . in temperature at Batavia and of 1 cm./sec. in wind at Mauritius.

Prof. Chapman's paper was largely a survey of concrete results and so there was very little discussion.

The second paper, in complete contrast, was mainly conjectural ; in fact, the observations available to verify the mechanisms described are extremely scanty.

The tropopause was defined as the transition between a lower layer of the atmosphere (the troposphere) in which transfer of heat is by convection, and an upper (the stratosphere) in which transfer of heat is by radiation. As absorption of the short-wave radiation from the sun is negligible near the tropopause, the distribution of temperature in the lower stratosphere, under stable conditions, depends mainly upon the absorption of long-wave radiation from the surface of the earth. No account was taken of the movement of air masses.

The nature of the change of temperature from troposphere to stratosphere was first considered ; it was shown that the most stable type of tropopause occurred when the lower stratosphere was isothermal.

In the latter half of the paper, arguments were put forward to explain latitudinal and seasonal variations of temperature. The latitudinal variations gave rise to much discussion. Assuming a constant lapse rate (6.5°C./Km.) of temperature in the troposphere, Mr. Goody focussed attention upon the relative amounts of heat absorbed by the stratospheric gases in different latitudes. Dobson had concluded that, in the stratosphere, temperature depended upon the proportions of ozone and water vapour, and the high temperatures over polar regions were due to high concentration of ozone. Contrary to this conclusion, Mr. Goody considered that the effect of ozone at the tropopause was a small heating effect nearly constant with latitude. Cooling was greatest with gases which thinned most rapidly with height. In latitude 70° the principal cooling agent was water vapour, in the tropics it was carbon dioxide. Variations in the absorption of heat by these gases were, to a first approximation, dependent only upon temperature and pressure at the tropopause ; warming due to water vapour decreased with increasing temperature

*CHAPMAN, S. ; Atmospheric oscillations. *Nature, London*, **159**, 1947, p. 357.

†1 microbar = 0.001 mb.

whilst that due to carbon dioxide increased with both temperature and pressure. The effect of carbon dioxide accounted for the latitudinal variation of stratosphere temperature—low over the tropics and high over the poles—being the reverse of that in the troposphere. With a constant lapse rate in the troposphere, the higher ground temperature in the tropics was associated with a higher tropopause, the temperature at which convection ceased being reached less quickly. Pressure at the tropopause therefore tended to be lower, causing absorption by carbon dioxide to be less, and, other effects being constant, this explained the occurrence of lower temperatures over the tropics than over high latitudes.

The discussion showed approval of Mr. Goody's simple and plausible explanations but disappointment concerning the many factors omitted in deriving these explanations. No account had been taken of the differing wavelengths of the radiant heat absorbed by the different gases ; and no mention had been made of advection, a probable cause of the clear-air gusts (jet streams) encountered by aircraft at tropopause level. Those taking part in the discussions were Prof. Brunt, Dr. Dobson, Dr. Scott Temple, Mr. Gold, Mr. Durst and Mr. Brewer. Dr. Dobson referred especially to the need for laboratory measurements of the absorption of gases in condition similar to those in the upper air

ROYAL ASTRONOMICAL SOCIETY

A geophysical discussion on "Wind and ocean currents" was held by the Royal Astronomical Society at 4.30 p.m. on November 26, 1948.

Dr. Doodson opened the meeting with a brief outline of the problems involved in the treatment of water movement in relation to wind. The scale of the various phenomena varies from the molecular to that of large oceanic circulations. In wave motion the occurrence of critical values must be emphasised. Jeffreys has shown that there exists a minimum wind velocity of the order of 100 cm./sec. necessary to create waves and recently a new critical velocity has been found. This velocity of some 700 cm./sec. marks the threshold between "smooth", or laminar, flow and "rough", or turbulent, flow and corresponds with the common experience of the occurrence of "white horses" with winds of Beaufort force 3-4 and over. Other problems on waves include their growth by absorption of energy from the wind, the transport of volume by wave motion and, as a consequence, the effect of the rotation of the earth.

Dr. Doodson then mentioned the classical work of Ekman on the theory of drift currents in an infinite ocean and briefly referred to the effect of boundaries and surface gradients made apparent in shallow seas.

Dr. Deacon, following, dealt in broad general terms with the inter-relationship between wind and current and emphasised the complexity of the problems. He showed vertical sections (due to Wüst) of the general oceanic circulation in the Atlantic Ocean, based on data from the German *Meteor* expedition and pointed out the different water-mass movements. Originally, Rennell had attributed currents to the direct effect of the wind and did not attach any importance to the specific gravity distribution. The American, M. F. Maury, on the other hand, placed great emphasis on the distribution of specific gravity and regarded the effects of the winds as local and transitory, this extreme point of view being very evident in his "Geography of the sea" and "Sailing directions". Since that time oceanographers have tended towards one extreme

or the other and the argument exists in milder fashion even today. Dr. Deacon took pains to point out that he regarded the specific gravity distribution as playing but a minor role, capable of producing currents of a few centimetres per second but quite incapable of producing currents of the order of knots. In his view wind is the predominant generator of current.

Some interesting diagrams, taken from a recent paper by Stommel, were then shown. Stommel has sought to apply the theory of wind-driven currents to explain the intensification of the currents on the western borders of the oceans, examples being the Gulf Stream and the Kuroshio. By idealising an ocean into a rectangle with the trade winds blowing along the southern boundary and the westerlies along the northern boundary, a simple mathematical argument leads to a picture of stream-lines with both east-west and north-south symmetry for the cases of a non-rotating and a uniformly-rotating ocean. In the real ocean, however, the Coriolis force is a function of the latitude. Assuming a linear function for simplicity (this is good enough in low latitudes), Stommel demonstrates that the revised stream-line pattern is non-symmetrical in the east-west direction, showing a marked concentration of stream-lines along the western boundary.

Dr. Deacon made a brief reference to Ekman's work and then remarked on a discrepancy between the demands of the drift-current theory and the theory of wave formation. The drift-current theory requires much higher values of the eddy viscosity than can be reconciled with the theory of the formation and dissipation of surface waves. Some interesting experiments by Woodcock on convection cells in the ocean were then described. These cells show an asymmetry which, as suggested by Munk, can probably be attributed to the effect of the earth's rotation.

Mr. Ursell then presented a mathematical paper in which he sought for the conditions under which waves could give rise to currents. Assuming, initially, a steady state in which waves of small amplitude are propagated without change of shape on a flat rotating earth he showed from the equations of motion that there can be no mass transport along the crests and then, by applying the circulation theorem, that there can be no transport in the line of advance of the waves. If, however, we now consider a system of waves (swell) moving into an area of still water the resulting wave motion must be non-rotational since it is generated from rest and therefore the waves must be of the Stokes type, and cannot be Gerstner waves which are rotational. Stokes waves possess mass transport and therefore it would appear that a swell can give rise to a component of current.

Mr. Corkan then described, at length, the work carried out by Dr. Doodson and himself on meteorological or storm surges in the North Sea. The difference between the actual tide at a place and the astronomical or predicted tide adjusted for distortion must be due to the meteorological factors, wind and atmospheric pressure. It is usual to eliminate the effects of barometric pressure by assuming that the hydrostatic law is an adequate approximation. In the theory it is usual to regard the North Sea as a canal with a boundary across the Straits of Dover and open to the ocean at its northern end. Storm effects may then be divided into two classes, internal effects which can be dealt with on theoretical lines and external effects which enter the North Sea from the north and travel southwards like a progressive wave. It is possible to forecast the

incidence of external storm surges at Southend by noting the time they pass some point further north. In practice it is found that the time interval of travel between Dunbar and Southend is about nine hours. These external surges may be due to the effect of the travel of depressions east and north-east to the north of the British Isles. Mr. Corkan went on to show how the data gained in this work can be utilised to determine the values of the eddy viscosity and the damping factor. The free period of the North Sea was estimated to be of the order of 30 hours. Those interested in storm surges will find further details in an article by the speaker which appeared in *The Dock and Harbour Authority*, February 1948. An abridged version of this article has been published in the *Marine Observer* (January 1949).

Other speakers included Sir Geoffrey Taylor, Prof. Sheppard and Mr. Durst.

In his concluding remarks Dr. Doodson regretted that there was insufficient time for an adequate discussion of the broader issues involved owing to the time taken by the opening speakers. This sentiment was shared by most of the meteorologists present.

T. H. KIRK.

FRENCH INSTITUTE, LONDON

A talk on the "Light of the night sky" was given by Prof. Cabannes of the Sorbonne, Paris, at the French Institute in London on Tuesday November 23, 1948. Prof. E. N. da C. Andrade introduced the speaker.

Prof. Cabannes began by illustrating the existence of the light of the night sky by showing lantern slides of photographs taken by the aid of this light alone. After describing the work at the observatory at the Pic du Midi and also the spectrograph used in the experiments, he went on to discuss the nature and origin of the phenomena observed.

The spectrographic plates showed that the night sky radiates energy of a total intensity too great to be explained by starlight alone, and that, in fact, 56 per cent. of the continuous spectrum was to be accounted for.

The theory that this portion may be due to radiations from interplanetary space has been tested by examining the polarization of the incoming light. The slight degree of polarization detected suggests that part may be due to this source, equivalent to an extension of the zodiacal light. Calculations give a possible 15 per cent., leaving 41 per cent. still to be explained.

The light emitted by the stars is dispersed by the particles in its path, which results in an apparent magnification of the size of a star as observed on the earth. This magnification is found to be selective as regards the wavelength of the light, indicating a selective absorption which does not comply with the Rayleigh scattering formula but which can be explained, by the aid of Mie's equations, as being due to absorption by particles of molecular size, not electrons or large particles. Light scattered by molecules in space in this manner is estimated to contribute 10 per cent. to the total continuous spectrum of the night sky.

Researches by Barbier show that the remaining 31 per cent. originates in the earth's atmosphere. Comparisons made between the spectra of the night sky and those of the sun determined the characteristic lines from this source as the green and the red oxygen lines and the sodium line, which indicated the

presence of sodium atoms in the upper atmosphere, also the nitrogen bands having a distinctive sharp boundary. These lines were explained by energy changes taking place between atoms in a metastable state through the agency of a third particle which could be a molecule of the same element.

Examination of the energy of the light of the night sky by Dufay has determined the lines and bands due to these three-particle collisions in the upper atmosphere. He has also shown that a close correlation exists between their intensity and the activity of sunspots.

D. D. CLARK

LETTERS TO THE EDITOR

Barograms from big ships—action of ocean waves and gusty winds

The development by the Instruments Branch of the Meteorological Office of an arrangement whereby an open-scale barograph can be taken to sea in a small ship and give a trace as fine, and almost as reliable, as at a land station is a remarkable achievement. Mr. Bibby's introductory statement of the problem in his account of this development* seems, however, to contain some misconceptions regarding the behaviour of the bigger ships at sea, which should be corrected if we are to avoid false conclusions about the magnitude of the pressure fluctuations in a turbulent atmosphere over the sea from examination of their barograms.

The whaling-factory ship *Balaena*, on which I spent over five months in the Southern Ocean, is a vessel of over 15,000 registered tons. Her behaviour as regards rolling and pitching would therefore approximate more closely to that of a large passenger liner than to an ocean weather ship, though we may presume that the vibration caused by the winches used in dismembering whale carcasses must be far greater than any vibration experienced on a great passenger ship. Yet the *Balaena* barograms show that occasional broadening of the trace was almost entirely due to the rolling and pitching of the ship in heavy sea.

As we read in the newspapers of occasional damage to furniture and fittings and injury to passengers on even the largest and most modern ocean liners in North Atlantic storms in winter, it is fair to assume that on these vessels also the movement of the ships in heavy seas is of more account than mechanical vibration or any possible fluctuations of pressure due to gustiness of the wind. Indeed it is only in the seas accompanying winds between force 4 and force 6 that the larger vessels are likely to give appreciably smoother traces than the smaller craft.

These conclusions may be illustrated by the *Balaena* barograms shown in Figs. 1, 2 and 3, facing p. 52. The instrument was an ordinary open-scale barograph as used at land-stations†, mounted on an eight-times folded soft woollen blanket. This mounting was roughly equivalent to the rubber-pad mounting used in the experiment on board O.W.S. *Weather Observer*, and was used throughout the voyage after early experiments with various suspensions had shown that it was the best that could be contrived with the materials available on board. Winds were measured with a revolving-cup anemometer installation.

*BIBBY, J. R. ; The use of barographs in ships. *Met. Mag., London*, 77, 1948, p. 176.

†The traces have been photographically reduced in size a little.

It should be explained that where the pack-ice afforded shelter heavy seas did not invariably accompany strong winds, and the effects of each could therefore be studied separately. The conclusion was soon reached that any broadening of the trace could be taken as a certain indicator of moderate to heavy seas. It was probably also affected by the orientation and speed of the vessel with respect to the waves.

The broadest traces—3–3½ mb. broad—were recorded on the outward and homeward voyages when *Balaena* was steaming through the heavy swells of the roaring forties and fifties, actually with winds between Beaufort force 5 and 8.

The trace for February 24–26, 1947 (Fig. 1) includes a period near the ice in 65°S. 113°E. when a SE., force 11, wind was observed, and swell was less severe than in the crossings of the open ocean. Successive observations were as follows:—

Date	Time	Wind	Sea
	G.M.T.		
24.2.47	1200	SE'E. force 7, gusty	Heavy NE. swell
	1800	ESE. force 9	—
25.2.47	0000	SE. force 11	Heavy E. swell
	0600	SE. force 9	Moderate E. swell
	1200	SE'S. force 6	No swell
	1800	SSE. force 5	—
26.2.47	0000	S'E. force 4	No swell

The waves described as swell in these observations were all about 100 m. long, from crest to crest ; heavy swell means waves over 4 m. high, from crest to trough, and moderate swell means waves between 2 and 4 m. high. Swell was not observed in darkness at 1800 G.M.T. It will be noticed that the barograph trace became fine as soon as the swell ceased, although the wind was still force 6 or over. The heading of the vessel varied during the period.

The trace for March 3–5, 1947 (Fig. 2), recorded near the same position, is also interesting. At 1200 G.M.T. on the 3rd the wind was SE'E. force 8, with only a slight swell, less than 2 m. high, and the trace was still quite smooth although the wind had been force 6 or more for over twelve hours. The next observations were as follows :—

Date	Time	Wind	Sea
	G.M.T.		
3.3.47	1800	SE. force 9	No swell or sea observations on account of darkness.
4.3.47	0000	SE. for. 7, gusty	Moderate NE. swell
	0600	SE. force 6, gusty	Moderate NE. swell
	1200	SE. force 5, gusty	Moderate NW. swell
	1800	SE. force 6	—
5.3.47	0000	ESE. force 5	Moderate WNW. swell
	0600	E'S. force 4	Slight WNW. swell

It will be noticed from Fig. 2 that the trace did not begin to broaden until about 2300 G.M.T. on the 3rd, *i.e.* when the wind had already begun to moderate. The broad trace continued until about 0600 G.M.T. on the 5th, when the swell disappeared. During this period the wind was at times only force 4–5. The gustiness referred to in some of these observations was of the type of minor squalliness commonly associated with unstable air. The north-westerly swell

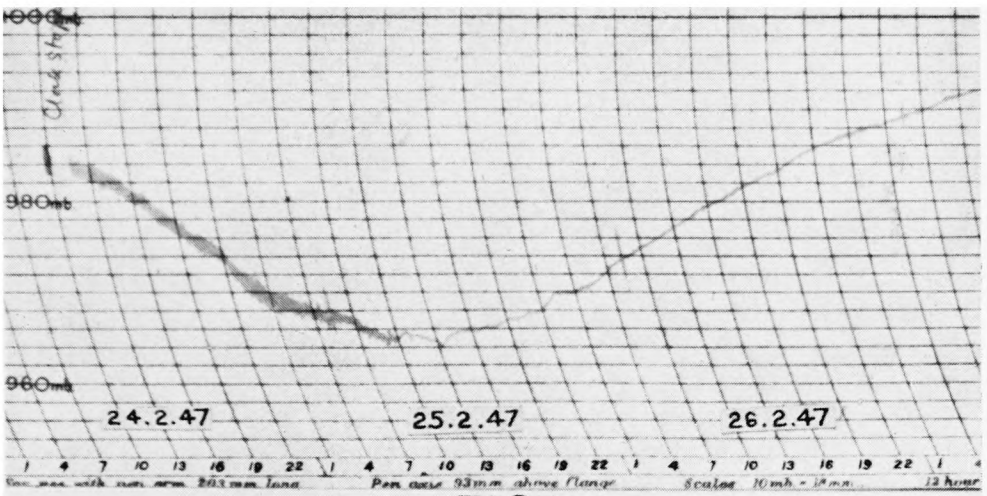


FIG. 1

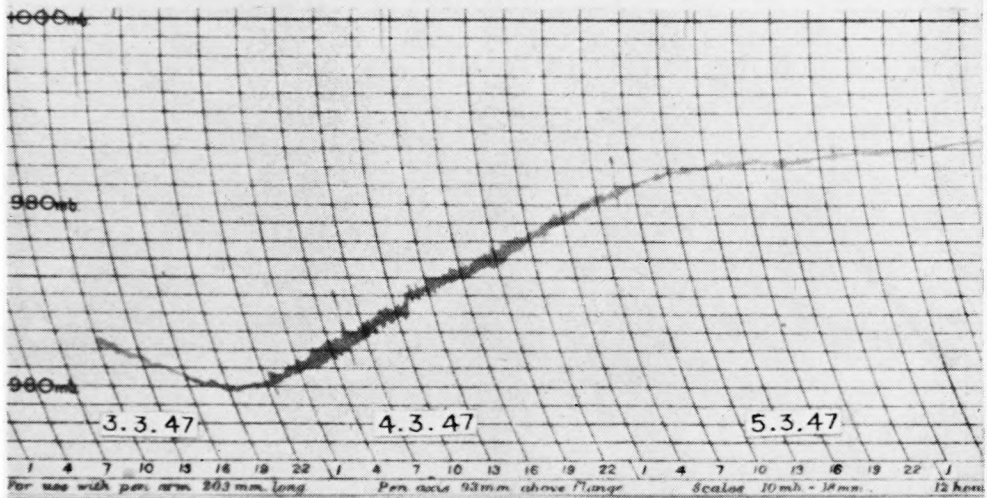


FIG. 2

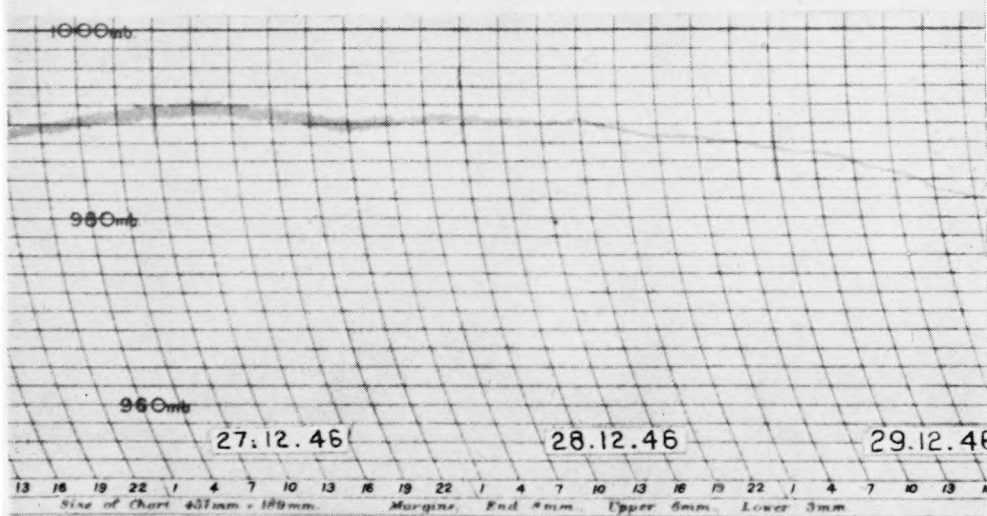


FIG. 3

To face page 53]



RIME AT SYERSTON, NOTTINGHAMSHIRE, NOVEMBER 23, 1948

(see p. 54)

reported was a long swell, over 200 m. from crest to crest, and was evidently set up by strong winds elsewhere over the open ocean to the north.

Finally we may examine the trace recorded on December 27–28, 1946, near 58°S. 80°E. (Fig. 3). On the 27th the trace was over 1-mb. broad although the wind was force 1 at most of the observations : there was a moderate, and at one time heavy, northerly swell. The full observations were as followed :—

Date	Time	Wind	Sea
	G.M.T.		
27.12.46	0000	NNW. force 1	—
	0600	N. force 1	Heavy N. swell
	1200	NW. force 1	Moderate NW. swell
	1800	NNE. force 3	Moderate N. swell
28.12.46	0000	NE. force 2	—
	0600	NE. force 3	Slight N. swell
	1200	E. force 3	Slight NE. swell
	1800	E. force 3	No swell

The gradual improvement in fineness of the trace on the 28th clearly corresponded to the diminishing swell.

No doubt a vessel, particularly a large vessel, will set up eddies in the wind stream which are usually an almost stationary feature of the flow pattern. There is no reason to suppose, however, that this will have even as much effect on the barograph as the gusts representing moving eddies which pass over a land station.

It is true, too, that the observer on a big ship (particularly if he is high above the water-line) will be aware of a regular rising and falling of the relative wind as the ship, riding the bigger waves, sways to and fro in the wind stream.

In general, however, gustiness is less noticeable at sea than over the land, and we conclude that it is the movement of the vessel which is chiefly responsible for broadening the barograph traces. There is no evidence in these examples of any appreciable effect due to gustiness.

H. H. LAMB

September 3, 1948

[The first section of my article admittedly contained a good deal of conjecture, and Mr. Lamb's first-hand observations are therefore especially welcome. It would be interesting to know if he came to any conclusion about the exact cause of the movement of the barograph pen ; whether it was mechanical acceleration or pressure oscillations induced by the swell. It should be possible to decide this by carefully noting the phase of the pen oscillation relative to that of the ship. Evidence on this point from ocean weather ships' officers would also be valuable, as indicating whether small ships are affected differently ; and also whether a further improvement in ships' barographs would be obtained by counterbalancing the pen arm.—J. R. BIBBY].

Rime at Leeming on November 23, 1948

There was widespread deposition of rime on trees and shrubs in the vicinity of the R.A.F. Station at Leeming on November 23, 1948. Fig. 1, facing p. 40, and Figs. 2 and 3, facing p. 41, show the deposition on a cobweb and on trees and shrubs.

The close-up, Fig. 3, is the most impressive showing the formation of rime ice only on the windward (south-south-easterly) side of twigs and leaves, and shows the original approximately three-quarters natural size. This is the surface

equivalent of rime accretion on the leading edges of aircraft flying in clouds, and is formed in an identical manner by small supercooled water droplets being disturbed by impact with an obstruction. The ice build-up consisted of small soft white ice pellets loosely joined, and the light south-south-easterly wind was sufficient to shake them off the foliage and give rise to a shallow carpet of "snow". Roads overhung by large trees were made treacherous in this manner. Figs. 1 and 2 were taken at 0930 and Fig. 3 at 1430 on November 23.

Summary of weather conditions from 1900 November 22 to 1430 November 23.—Screen air temperature fell below freezing point at 1900 on the 22nd and remained below freezing with minimum temperature 22°F.; the air became saturated at 2200 and remained saturated; fog (visibility below 1,100 yd.) first formed at 0100 on the 23rd and persisted; and the surface wind was calm until 0400 on the 23rd becoming south-south-easterly 2–4 m.p.h. thereafter.

Weather at 0930 November 23.—Fog, sky obscured, visibility 200 yd., wind south-south-easterly 3 m.p.h., temperature 25°F., and relative humidity 100 per cent.

Weather at 1430 November 23.—Fog, sky obscured, visibility 80 yd., wind south-south-easterly 2 m.p.h., temperature 28°F., and relative humidity 100 per cent.

B. FOX-HOLMES

Leeming, Yorks, November 23, 1948

Rime at Syerston, Nottinghamshire

The two photographs (facing p. 53) of rime formation at Syerston are thought to be of interest. The formation occurred on the night of November 22 to 23, 1948, which was a period of dense fog with a night minimum temperature of 29°F. and surface wind light south-westerly or calm.

The formation was about an inch in length and on twigs from an eighth to a quarter of an inch in diameter.

F. F. HARRINGTON

Syerston, Notts., November 26, 1948.

NOTES AND NEWS

Meteorological pamphlets presented by Mr. C. E. Britton

Mr. C. E. Britton has followed his gift of old meteorological prints* for the decoration of the conference room at Victory House, by presenting some old and rare meteorological pamphlets to the Meteorological Office Library.

Among the more interesting of these old pamphlets may be mentioned:—

(a) A description of the well known destruction by lightning of the church at Widecombe in the Moor, Devonshire, on October 21, 1638. This contemporary account is in a relatively matter-of-fact style for the times and is free from the fantastic embellishments found in others.

(b) A pamphlet on the floods in the north of England in November 1771 following three days continuous rain. Among the events described is the washing of peat from Solway Moss over a large agricultural area.

(c) An astrological almanac for the years 1648–50 by the well known astronomer William Lilly. Included in this almanac is an account of mock

*.cc *Met. Mag.*, London, 77, 1948, p. 233.

suns seen in Lancashire on February 28, 1648. The observer of the mock suns in his letter to Lilly said he thought they were due to "naturall causes being but the brightness of the Suns beams, from a cloud reflected on the earth", but asked, nevertheless, for Lilly's "Astrologicall judgement hereupon" which was duly provided in full measure.

(d) An account in Latin of mock suns seen at Wittenberg in Saxony on January 11, 1736. There is no astrology in this pamphlet, by John Wiedler and dedicated to the secretary of the Royal Society, which contains a lengthy dissertation on ancient and modern observations and theories of mock suns. Greater prominence is given to Descartes' and Huyghens' somewhat fantastic theories, which were only correct in that they did attribute the phenomena to refraction, than to Mariotte's theory, which is correctly based on refraction through ice prisms. The pamphlet gives also an account of an aurora seen over Europe as far south as Rome on December 16, 1736.

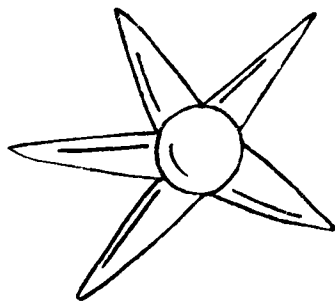
(e) Contemporary broadsheets descriptive of the burning of a ship off Gravesend in 1687 after being struck by lightning, the snowstorms of December 23, 1684, and early March 1674, and a newspaper cutting on the Frost Fair on the Thames in December 1813 and January 1814.

Unusual hailstones

The following account of unusual hailstones, sent to us by Mrs. P. O. Bickford of Kapsaret Estate, Eldoret ($0^{\circ}35'N$. $35^{\circ}20'E$. 7,000 ft.), may be of interest.

"On Friday August 6 on this Estate, 8 miles from Eldoret on the Kapsaret road, at 5 p.m., there occurred a rather singular fall of hail which I thought might be of interest to you, though it may be quite familiar to you.

The sky became very dark and large hailstones fell, but in the shape of stars similar to those of snow crystals in shape (when seen under the microscope). They nearly all measured $1\frac{1}{2}$ in. in width. They consisted of large ice balls the size of a very large pea with fine radiating arms of ice. Some of these landed on their sides and stuck sideways on in the grass. These soon gave way to rain. Some were of a squarish shape but these were not perfect."



There was a zone of convergence over this area between south-easterly and south-westerly winds on August 6 with the freezing level at 15,000 ft.

W. A. GRINSTED

Nairobi, Kenya, August 31, 1948

[Hailstones of this shape are very rare. A photograph of one which fell in Germany in 1898 is given in "Physik der Atmosphäre" by A. Wegener and K. Wegener (Leipzig, 1935), p. 174 copied from *Met. Z. Braunschweig*, **15**, 1898, p. 41.—Ed. M.M.]

REVIEWS

On the thermal structure of the atmosphere over Agra, by R. Ananthakrishnan. Memoirs of the India Meteorological Department, Vol. XXVII, Part IV, 4to, 12 in. × 9½ in., pp. 61–100, *Illus.*, Delhi, Manager of Publications, 1948. Price: Rs. 2 or 3s.

Thanks to the comprehensive programmes of upper air soundings carried out by the India Meteorological Department, the characteristics of the atmosphere over Agra are probably better known than those over almost any other place outside Europe and North America. Nevertheless, the new study by R. Ananthakrishnan, presenting monthly mean values based on ten years' records is a welcome addition to our knowledge of the free atmosphere.

The author pays particular attention to the lapse rate and to the occurrence of inversions. As he points out, statistical treatment of the tropopause is difficult because of its complex structure in winter, but the figures given, which are based on the mean lapse rate, will leave out of account the lower branch of many occasions of double tropopause and may be misleading.

In discussing the factors controlling the temperature of the upper troposphere the author rightly emphasises the radiation balance in the dry season and the latent heat released by convection in the monsoon.

J. S. SAWYER

British Thunderstorms. Sixth Report, 1936–37, Vol. 2, Part 3, 8vo, 8½ in. × 5½ in., pp. 97–144, *Illus.*, Huddersfield, Thunderstorm Census Organisation, 1948. Price 5s.

This report is a survey in time and space of the thunderstorms over the British Isles for the years 1936 and 1937, set out in the following manner. There is a synopsis of the results in two tables of the number of days with thunder and lightning in England, Wales, Scotland, Ireland and the British Isles for each month from October 1935 to December 1937. There are also descriptive notes on the thundery activity of each month of the years 1936 and 1937 illustrated by quarterly and monthly maps in black and green of the number of days with storms and a report by T. E. Dark on trees struck by lightning. Finally there is a detailed descriptive account of the widespread outbreak of thunderstorms on July 15, 1937, illustrated by a rainfall map of that day and another of hourly isochrones. Included in the volume are reviews of a number of some recent publications on thunderstorms and lightning.

We are greatly indebted to the Thunderstorm Organization for collecting this data in so handy a form. To the reviewer the display of the elemental forces, so prodigally released in a severe thunderstorm, is the most awe-inspiring experience of power and might in the world. We are tempted to ask for greater detail. From the academic and practical points of view something more is needed for the apprehension of a thunderstorm than a record of thunder heard or lightning seen. It is suggested that there should be given, for different places, monthly tables giving dates and times of onset and termination of each storm as well as its severity and direction of motion, the number of the flashes seen, especially those to earth, and remarks on any interesting associated phenomenon, e.g. hail, squalls, lightning damage, fall of temperature, rise of pressure and changes of wind direction. The recording of many of these items in the tables could be simplified by a code of numbers. If space does not permit of this, monthly frequency tables of the different data could be given for each place as well as detailed data for the outstandingly severe storms.

When data extends over a number of years it is always more satisfactory to have the more recent information first. In this connexion it is suggested that the data for the more recent years be published first. It is satisfactory to note, however, that a summary for 1946 has been included as a loose leaflet in this volume.

J. E. BELASCO

A low pressure portable hydrogen generator for pilot balloon observatories. By L. S. Mathur. Scientific Notes of the India Meteorological Department. Vol. IX, No. 114. 8vo. pp. 161-5. *Illus.*, Delhi, Manager of Publications, 1948. Price : Annas 0-5-0 or 6d.

This paper describes a silicol-caustic-soda-type low-pressure hydrogen generator for use in inflating pilot balloons. The generator is, in general, similar to other generators serving the same purpose. It consists of a generator unit and a scrubber unit for cooling the gas after generation.

Measured quantities of boiling water and caustic soda are first placed in the generator, after which its lid is bolted down. A measured quantity of powdered ferro-silicon is then introduced into the generator through a special fitting in the lid and generation of hydrogen takes place. The gas from the generator is fed into the scrubber where it bubbles through water which cools it and traps any fine alkali spray which may be carried over by the gas. The outlet from the scrubber has a double-sized nozzle, to accommodate balloon necks of various sizes, and a stop cock. Two points of particular interest are :—

(1) The use of boiling water to start with ; when generators of this type are started from cold, there are occasions when the reaction is either very slow or does not start at all.

(2) The method of introduction of the ferro-silicon charge, which can be done without losing any appreciable quantity of gas from the generator.

No safety valve appears to be fitted. The description includes a table of quantities of chemicals required for various sizes of balloons, full instructions for use, and a list of safety precautions. There are three pages of illustrations which make the description easy to follow.

G. E. W. HARTLEY

WEATHER OF DECEMBER 1948

From the 1st to the 15th pressure was generally high on the continent and low out on the Atlantic, and several secondary depressions moved northwards or north-eastwards across the western parts of the British Isles between the 5th and the 10th. After a large anticyclone had developed over France on the 16th, pressure was rather high until the 27th, reaching 1040 mb. locally from the 19th to the 21st. Troughs of low pressure then moved eastwards across the country, and the month ended with pressure below 960 mb. in the west of Ireland.

Mean pressure for the month was above 1030 mb. in the northern part of the Balkans and above 1020 mb. over southern and central Europe and the Mediterranean. It was below 1000 mb. over a large area south-westward of Iceland, and was about 993 mb. in 60°N. 30°W. The mean was more than 10 mb. above normal in the northern part of the Balkans and more than 5 mb. below normal southward of Iceland.

Over the British Isles the weather was unusually mild and unsettled during the first half of the month. Subsequently cold, dry weather prevailed until the 26th in the west and the 28th in eastern districts. Thereafter unsettled conditions were renewed and persisted until the end of the month.

The cold, foggy weather experienced at the end of November continued in some eastern districts until the evening of December 1. Broadly speaking, from the 1st to 15th a complex area of low pressure was situated in the north-east Atlantic, while secondary disturbances formed westward of the Azores and moved rather quickly east and then either north-north-east along the western seaboard of the British Isles or north-east across the country. The air flow over the British Isles was drawn from the neighbourhood of the Azores and temperature was notably high for the time of year. Rain occurred frequently and was heavy locally at times, particularly in the west. Thunderstorms were recorded locally from the 6th to 9th and were rather widespread in the southern half of England on the 13th and 14th. Winds were often strong and gale force was reached at exposed stations on a number of days, particularly in the west. Among the heavier falls of rain in 24 hours during this period were 3·81 in. at Llyn-y-fan Fach, Carmarthen, and 3·74 in. at Trecastle, Brecon, on the 2nd, 2·97 in. at Gruline, Mull, and 2·40 in. at Florencecourt, Co. Fermanagh, on the 5th, and 2·75 in. at Watendlath, Cumberland, on the 11th.

From the 15th to 18th an anticyclone near the Azores and a ridge westward of the British Isles moved north-east, and subsequently high pressure was established on the continent with a ridge extending west over the British Isles. Temperature fell appreciably and there was little or no rainfall. By the 21st pressure was highest in an anticyclone centred near Thorshavn and, during the following days this system moved south-south-east to combine with a high over central and south-east Europe. Over the British Isles weather continued dry and cold, the 26th and 27th being particularly cold in parts of England and south Scotland; for example, at Honiley in Warwickshire, temperature remained continuously below freezing point on these days, while a screen minimum temperature of 15°F. was registered at Bristol on the 26th and one of 17°F. at Mildenhall, Suffolk, on the 27th.

A change to unsettled conditions took place in the west on the 26th and 27th. On the 28th a trough of low pressure, associated with a very deep depression moving north-east across Iceland, moved over the British Isles giving strong winds, local gales and considerable rainfall. On the 30th a secondary depression moving east-south-east over southern districts gave snow from Wales to the Humber and Wash areas amounting to 12 in. at Wirksworth, Derbyshire, and 8 in. at Mansfield, Nottinghamshire, and heavy rain a little further south. On the closing day a depression developed on the Atlantic and moved rapidly eastward, deepening as it moved and by midnight pressure had fallen to the extremely low level of 957 mb. in north-west Ireland and was still falling. Among falls of more than 2 in. of rain were 2·11 in. at Inveraray Castle, Argyll, on the 28th, 2·41 in. at Beulah, Brecon, on the 30th and 2·25 in. at Rhondda Water Works, Glamorgan, on the 31st.

The general character of the weather is shown by the following provisional figures.

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	62	13	+2·0	114	—2	134	23
Scotland	65	14	+2·1	112	—2	103	16
Northern Ireland..	62	22	+1·5	146	—2	123	22

RAINFALL OF DECEMBER 1948

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	2.20	92	<i>Glam.</i>	Cardiff, Penylan ..	4.95	99
<i>Kent</i>	Folkestone, Cherry Gdns.	2.32	72	<i>Pemb.</i>	St. Ann's Head ..	4.76	100
"	Edenbridge, Falconhurst	4.47	135	<i>Card.</i>	Aberystwyth ..	6.16	155
<i>Sussex</i>	Compton, Compton Ho.	5.67	135	<i>Radnor</i>	Bir. W. W., Tyrmynydd	12.15	148
"	Worthing, Beach Ho.Pk.	2.89	96	<i>Mont.</i>	Lake Vyrnwy ..	7.31	105
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	3.86	117	<i>Mer.</i>	Blaenau Festiniog ..	10.15	80
"	Bournemouth ..	5.16	133	<i>Carn.</i>	Llandudno ..	4.25	147
"	Sherborne St. John ..	4.63	141	<i>Angl.</i>	Llanerchymedd ..	4.67	106
<i>Herts.</i>	Royston, Therfield Rec.	1.86	80	<i>I. Man.</i>	Douglas, Boro' Cem. ..	4.90	99
<i>Bucks.</i>	Slough, Upton ..	3.17	126	<i>Wigtown</i>	Port William, Monreith	4.41	97
<i>Oxford</i>	Oxford, Radcliffe ..	2.70	110	<i>Dumf.</i>	Dumfries, Crichton R.I.	6.09	142
<i>N'hant.</i>	Wellingboro', Swanspool	2.77	118	"	Eskdalemuir Obsy. ..	7.89	113
<i>Essex</i>	Shoeburyness ..	1.72	93	<i>Roxb.</i>	Kelso, Floors ..	1.88	81
<i>Suffolk</i>	Campsea Ashe, High Ho.	.93	40	<i>Peebles</i>	Stobo Castle ..	5.40	142
"	Lowestoft Sec. School ..	1.56	67	<i>Berwick</i>	Marchmont House ..	2.10	75
"	Bury St. Ed., Westley H.	1.75	73	<i>E. Loth.</i>	North Berwick Res. ..	1.39	65
<i>Norfolk</i>	Sandringham Ho. Gdns.	2.05	81	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	2.20	94
<i>Wilks.</i>	Bishops Cannings ..	3.88	118	<i> Lanark</i>	Hamilton W. W., T'nhill	5.32	123
<i>Dorset</i>	Creech Grange ..	4.61	105	<i>Ayr</i>	Colmonell, Knockdolian	6.11	109
"	Beaminster, East St. ..	7.41	155	"	Glen Afton, Ayr San ..	9.29	145
<i>Devon</i>	Teignmouth, Den Gdns.	6.76	160	<i>Bute</i>	Rothsay, Arden Craig	7.71	141
"	Cullompton ..	5.92	135	<i>Argyll</i>	L. Sunart, Glenborrodale	11.01	126
"	Barnstaple, N. Dev. Ath.	4.38	99	"	Poltalloch ..	8.12	127
"	Okehampton, Uplands	10.80	153	"	Inveraray Castle ..	10.78	109
<i>Cornwall</i>	Bude School House ..	5.74	132	"	Islay, Eallabus ..	7.40	125
"	Penzance, Morrab Gdns.	7.38	130	"	Tiree ..	7.44	142
"	St. Austell, Trevarna ..	7.27	119	<i>Kinross</i>	Loch Leven Sluice ..	4.38	111
"	Scilly, Tresco Abbey ..	5.72	122	<i>Fife</i>	Leuchars Airfield ..	2.83	115
<i>Glos.</i>	Cirencester ..	4.44	125	<i>Perth</i>	Loch Dhu ..	14.16	140
<i>Salop.</i>	Church Stretton ..	3.84	109	"	Crieff, Strathearn Hyd.	7.21	161
"	Cheswardine Hall ..	3.67	130	"	Pitlochry, Fincastle ..	6.84	169
<i>Staffs.</i>	Leek, Wall Grange P.S.	4.00	107	<i>Angus</i>	Montrose, Sunnyside ..	3.89	140
<i>Worcs.</i>	Malvern, Free Library	3.87	140	<i>Aberd.</i>	Balmoral Castle Gdns. ..	4.62	137
<i>Warwick</i>	Birmingham, Edgbaston	5.00	186	"	Dyce, Craibstone ..	3.86	114
<i>Leics.</i>	Thornton Reservoir ..	3.64	136	"	Fyvie Castle ..	3.28	96
<i>Lincs.</i>	Boston, Skirbeck ..	2.63	122	<i>Moray</i>	Gordon Castle ..	2.12	79
"	Skegness, Marine Gdns.	2.99	136	<i>Nairn</i>	Nairn, Achareidh ..	1.83	89
<i>Notts.</i>	Mansfield, Carr Bank ..	2.98	103	<i>Inv's</i>	Loch Ness, Foyers ..	5.28	119
<i>Ches.</i>	Bidston Observatory ..	2.95	111	"	Glenquoich ..	13.36	91
<i>Lancs.</i>	Manchester, Whit. Park	2.99	92	"	Fort William, Teviot ..	9.73	95
"	Stonyhurst College ..	2.92	60	"	Skye, Duntuiln ..	7.98	128
"	Blackpool ..	2.74	84	<i>R. & C.</i>	Ullapool ..	4.39	72
<i>Yorks.</i>	Wakefield, Clarence Pk.	2.06	85	"	Applecross Gardens ..	7.73	120
"	Hull, Pearson Park ..	2.25	93	"	Achnashellach ..	7.05	74
"	Felixkirk, Mt. St. John	2.43	101	"	Stornoway Airfield ..	5.00	99
"	York Museum ..	2.13	95	<i>Suth.</i>	Lairg ..	4.06	101
"	Scarborough ..	1.54	65	"	Loch More, Achfary ..	7.81	85
"	Middlesbrough ..	1.17	60	<i>Caith.</i>	Wick Airfield ..	2.98	97
"	Baldersdale, Hury Res.	3.50	94	<i>Shet.</i>	Lerwick Observatory ..	5.74	120
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	1.89	80	<i>Ferm.</i>	Crom Castle ..	6.59	159
"	Bellingham, High Green	3.47	96	<i>Armagh</i>	Armagh Observatory ..	4.52	144
"	Lilburn Tower Gdns. ..	2.65	101	<i>Down</i>	Seaford ..	6.39	155
<i>Cumb.</i>	Geltsdale ..	2.89	76	<i>Antrim</i>	Aldergrove Airfield ..	4.48	131
"	Keswick, High Hill ..	8.17	122	"	Ballymena, Harryville ..	5.69	128
"	Ravenglass, The Grove	5.45	119	<i>Lon.</i>	Garvagh, Moneydig ..	6.27	156
<i>Mon.</i>	Abergavenny Larchfield	8.63	194	"	Londonderry, Creggan	6.16	141
<i>Glam.</i>	Ystalyfera, Wern House	13.58	162	<i>Tyrone</i>	Omagh, Edenfel ..	6.60	156

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, AUGUST 1948

STATIONS	PRESSURE		TEMPERATURES							REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE			
	Mean of day M.S.L.	Diff. from normal	Absolute			Mean values						Total	Diff. from normal	Days	Daily mean	Per- centage of possible	
			Max.	Min.	°F.	°F.	°F.	°F.	°F.								°F.
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.	hr.	%		
London, Kew Observatory	1012.9	-2.0	78	46	54.3	61.1	-1.1	56.9	77	8.1	2.87	+0.63	12	4.7	32		
Gibraltar	1016.0	-0.5	95	62	68.4	76.7	+0.7	70.3	78	3.1	0.00	—	0	11.3	84		
Malta	1015.1	+0.3	96	63	69.5	77.9	-1.2	72.5	62	0.6	0.00	—	0	12.5	93		
St. Helena	1018.9	-1.0	69	53	62.3	58.6	+1.3	54.7	93	9.7	1.37	-1.29	12	—	—		
Lungi, Sierra Leone	1013.7	—	84	70	80.0	76.7	—	73.8	93	9.5	47.59	—	27	—	—		
Lagos, Nigeria	1014.1	+1.1	85	63	81.2	75.1	-2.8	73.5	88	9.6	1.10	—	12	2.1	17		
Kaduna, Nigeria	1011.7	—	88	61	31.7	74.7	+0.5	—	—	—	12.07	-0.25	21	4.0	32		
Chileka, Nyasaland	1021.7	0.0	87	51	77.3	66.6	-0.6	58.3	62	2.3	0.02	-0.06	1	6.2	53		
Lusaka, Rhodesia	1019.0	+0.5	85	46	78.1	65.1	-0.4	53.2	55	2.0	0.00	0.00	0	9.2	79		
Salisbury, Rhodesia	1021.8	+0.2	81	40	72.5	59.3	-0.8	49.8	57	1.7	0.00	-0.10	0	8.6	75		
Cape Town	1021.5	+1.2	80	40	63.3	55.7	+3.4	47.8	69	5.5	2.00	-1.37	11	—	—		
Germiston, South Africa	1023.6	+0.7	79	35	71.8	58.3	+1.1	43.3	43	1.1	0.00	-0.25	0	10.3	92		
Mauritius	999.7	-1.0	92	75	89.4	84.3	+0.7	80.2	91	8.8	14.82	+1.44	25	3.5	27		
Calcutta, Alipore Obsy.	1003.7	-2.2	90	75	85.6	81.5	+0.7	76.9	87	8.4	17.03	+2.58	22	2.2	17		
Bombay	1004.1	-1.4	99	73	94.5	86.6	+0.6	75.5	70	7.4	3.49	-1.05	10	6.3	50		
Madras	1009.2	-0.1	86	73	84.7	80.9	-0.3	76.0	85	7.4	6.60	+3.36	12	7.3	59		
Colombo, Ceylon	1008.6	-0.9	92	72	88.3	82.5	+1.4	77.8	81	7.0	3.38	-4.57	15	—	—		
Singapore	1004.5	-0.3	92	75	88.5	83.3	+1.2	78.7	84	—	12.34	-2.06	19	7.2	56		
Hongkong	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Sydney, N.S.W.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Melbourne	1014.2	-3.8	69	35	60.4	52.1	+1.1	46.2	64	4.7	1.18	-0.69	12	5.5	51		
Adelaide	1016.5	-2.7	73	42	63.0	55.1	+1.1	49.3	63	5.3	2.57	+0.03	14	5.8	54		
Perth, W. Australia	1017.9	-1.0	81	39	66.8	58.5	+2.5	54.5	70	5.0	3.76	-1.89	12	6.9	63		
Geelong	1018.9	-0.4	82	39	68.4	56.9	+3.3	47.7	55	1.8	0.45	-0.54	9	—	—		
Brisbane	1018.2	-1.0	80	44	71.6	61.5	+1.1	54.7	62	3.5	1.35	-0.66	8	8.3	74		
Hobart, Tasmania	1008.4	-5.0	67	31	57.4	49.3	+1.3	43.7	68	6.4	0.77	-1.06	10	5.2	50		
Wellington, N.Z.	1017.2	+2.1	62	34	54.3	42.3	+1.0	45.6	81	6.2	2.28	-2.21	11	5.5	52		
Suva, Fiji	1013.6	-0.6	85	65	77.9	73.7	+0.1	69.9	81	8.0	5.86	-2.43	19	3.7	32		
Apia, Samoa	1011.3	-0.6	87	67	85.2	78.7	+0.2	75.2	77	5.7	3.03	-0.75	10	8.1	69		
Kingston, Jamaica	1013.5	0.0	93	72	91.3	83.3	+1.8	73.8	80	4.0	1.39	-2.16	5	7.5	59		
Grenada, W. Indies	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Toronto	1016.1	+0.7	101	52	80.9	70.9	+3.7	60.4	78	4.7	0.89	-1.90	23	8.5	61		
Winnipeg	1013.7	+0.5	91	42	79.6	67.7	+3.9	56.3	91	5.1	0.94	-1.22	7	8.2	57		
St. John, N.B.	1013.9	-1.4	87	49	71.7	63.0	+2.4	58.1	90	6.2	1.60	-2.26	10	7.4	53		
Victoria, B.C.	1016.1	-0.8	72	45	66.4	59.0	-0.7	52.8	93	6.8	2.58	+1.94	14	6.9	48		

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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FORECASTING RESEARCH

By R. C. SUTCLIFFE, Ph.D.

Any research, if it is a contribution to meteorological knowledge, can hardly fail to have value, immediate or potential, in weather forecasting. This is not a controversial statement for the forecaster is concerned with the evolution of meteorological conditions, with the changes taking place in the physical properties of the atmosphere, and research which throws no light on these things is hardly meteorology, however admirable it may otherwise be. Nevertheless, those who judge forecasting without first-hand experience may tend to regard it as concerned with a limited field of science, and to infer that research of value in forecasting must be highly specialised. This would misrepresent the case seriously and the true position may perhaps be illustrated by remarking upon the relevance to forecasting of a few lines of research selected from diverse fields less obviously apposite to the work of the forecaster.

A particularly good example is the study of climatic change through the ice ages—particularly good in that a very eminent meteorologist recently commended the subject to his colleagues as being not only fascinating but also, to the best of his belief, quite useless. He was on very unsafe ground. If we were to know with certainty the causes of climatic change in geological time we might hope to judge whether the same causes could explain the striking amelioration of winter climate in north-west Europe during the past century and to judge whether the trend would persist in the next decade, with no negligible significance for the economic recovery in these lands.

We need choose no special illustration from climatology; for this, even if we exclude synoptic climatology, is the background of past records which the forecaster ignores at his peril. Empirical forecasting, whether based on formulated rules or on experienced judgment, can be claimed as pure climatology—an integration of past events—and I would urge forecasters and climatologists to get closer together, the better to co-ordinate their research requirements.

It is rather in the field of physical experiment and theoretical research that we may expect to find something which by no stretch can be called forecasting research, but it is not easy. When M. Dessens succeeds so elegantly in capturing natural atmospheric nuclei on spiders' webs of fineness 1μ he may not be hoping to improve the weather forecast but he is nevertheless engaging on an essential and very promising line which in due course may decide whether

the forecaster must study nuclei conditions to predict some of the vagaries of fog, cloud and precipitation. Again, when Dr. Robinson, at Kew Observatory, studies radiation problems and gives us a modification of Elsasser's radiation chart he is well employed in the scheme of forecasting research; we need such results very badly indeed, for in both short-range and long-range problems we must judge in some way how the temperature of the free atmosphere will change. We might not hope to calculate the answer regularly from theoretical formulæ, this may prove for some time to be impracticable, but if we wish to develop even approximate methods we shall only be surely guided when the fundamental theory is well understood.

To take one last example, much highly theoretical and special experimental work is being carried out in connexion with evaporation and soil moisture with the application to agriculture immediately in mind; but the forecaster, apart from his direct agricultural interests, watches the progress with much interest and is already relating the results with his fog problem and with the more general question of the changes of moisture content in the free atmosphere.

If all meteorological research facilities in the country were controlled by the weather forecasters, and even if these people had a strictly utilitarian attitude, there might be some change of emphasis, of priorities, but I doubt whether the over-all picture would be very much altered. Even engineers recognise the need for fundamental research for practical ends; there is only one set of problems ultimately and the forecaster is concerned with them all.

And not only do I argue that all meteorological research is forecasting research but would affirm that experience in forecasting is the best introduction to almost any branch of meteorological research, whether climatological, experimental and observational, or theoretical. It may seem that to spend a year or a few years in predicting weather is a dubious investment for the research scientist; but this is not an informed point of view. The "forecaster", wherever he is employed, probably spends quite a small proportion of his time in predicting. Most of his efforts must go into studying present and past conditions, in co-ordinating the observations, analysing the situation and watching the course of change in the physical state of the atmosphere. The need to forecast is, perhaps, to the research mind, an irksome discipline but an entirely profitable one supplying just the necessary corrective to the wandering mind, to the eager theorist who would escape reality. Experience in a forecasting service, like little else, drives home the facts, such as they are known, about the atmosphere and allows the forecaster to formulate research problems about the real atmosphere—we may perhaps here agree that natural science should describe nature. If any young scientist is thinking of meteorological research as a career, whether he is a climatologist, a mathematician or an experimental physicist, I would quite cheerfully recommend him to spend a year or two letting his ideas take shape while he learns something about the atmosphere in the business of forecasting.

The above broad comments on the relationship between forecasting and research are, I think, a necessary preliminary if forecasting research proper is to be seen in true perspective and not as something rather outside the main stream of the science: its demands upon and its inspiration to research are all-embracing, its field co-extensive with the science of meteorology.

As, however, we do use the term "forecasting research" some limitation of scope must be implied; we are thinking of research which is specifically undertaken with the object of improving the standard or extending the scope of forecasting and to appreciate the requirements it is necessary to understand how the forecaster works—for forecasting is more than science, it is a professional occupation.

Weather forecasting, as traditionally carried out, follows a procedure which is in principle remarkably direct and simple to understand. The many observations of pressure, temperature and humidity, wind and weather phenomena, obtained from a wide area and made more or less synchronously, are plotted on geographical maps of the area and made surveyable by various cartographical methods. The result is, in effect, just a small-scale model of the atmosphere itself, represented, it is true, not as a solid model but by various sections and soundings, quasi-vertical and quasi-horizontal, yet providing to the forecaster a three-dimensional model of the atmosphere which he visualises as an entity. The process, which is conventionally referred to as the analysis of the situation, is actually a process of synthesis: from the many discrete observations the field distributions of the various properties and phenomena are inferred. From a sequence of observational material the synthesis is extended to the fourth dimension; the forecaster has in his mind the changing distribution patterns of pressure, temperature, wind and so on, synthesised from the observations, and forecasting is the extrapolation of the model into the future.

The technique of representation is fundamentally geographical or geometrical, primarily cartographical. It will be at once clear that success in forecasting by such model-making will depend on many factors and that the demands upon research will be diverse. The first requirement is adequate observations of adequate quality; the second, the development of cartographical techniques to represent the essential factors and features of the continuous fluid as completely and as clearly as possible; the third, technical skill in using the methods and in visualising the essentials of the actual atmosphere from the model provided—and this is where natural aptitude counts for much; the fourth, scientific skill in determining the most likely structure where observations are inadequate; and last, scientific skill in making the extrapolation into the future. I exclude, in connexion with research, the essential personal qualities, organising ability and general judgment, which are required for success in any profession: with so much to do the forecaster must above all keep his head.

It is therefore impossible to divorce forecasting research from the development of techniques, and it is obvious that skill in the actual prediction is interwoven with skill in the analysis and synthesis of observations. In the earliest days, as would be expected, there was an immediate jump forward to a considerable success based purely on experience and quite empirical extrapolation of the observed trends in the model. It would be impossible for any intelligent person, with the barest scientific knowledge, to miss the many obvious regularities, the more or less steady displacements and developments of circulation systems and rain areas, seasonal and topographical effects, diurnal variations and the like. These empirical methods elaborated and improved over the years remain a valuable part of forecasting, and, many will say, the greater part. It would however be quite untrue to regard established methods of forecasting as purely empirical, indeed there are few principles introduced which are not based

on physical insight or which have not been supported by physical argument and, in so far as exact formulæ are not established, the position should be not a discouragement but rather a challenge to the research scientist.

In a further article I hope to discuss in more detail the types of problems which arise and some of the more immediate lines of research and I may perhaps satisfactorily conclude this brief introductory survey with some very general comments on the probable trend of practical forecasting research in the next ten or twenty years. One avenue I may call the purely empirical: the use of organised statistical methods, correlation coefficients, regressions, periodicities and so on, which provide numerical values of physical quantities with statistically determined probable errors. This field has been worked over industriously; it has so far yielded very little, certainly nothing commensurate with the effort expended; it is still indeed far from being exhausted but, in spite of some new enthusiasm in certain quarters, I expect it to make no great impact on forecasting practice. I believe we know too much about the physical problems already to regard blind statistical research as a promising tool, although as a measure of the validity of methods inspired by physics the statistical analysis has its definite place.

At the other extreme is pure theory leading eventually, one may hope, to the calculation of the future state of the atmosphere with an accuracy restricted only by the uncertainties of "initial and boundary conditions". With or without the aid of electronic machines these methods are I believe still a long way off and I am not sure that much of the thought being put into the problem is not premature. The difficulty is that the fundamental differential equations are not yet adequately formulated. The magnitudes of the physical effects of radiation, turbulence and convection on the temperature of the free atmosphere, to take but one important factor, are not known with sufficient accuracy to allow calculation to be carried through successfully even in a simplified case. Further, topographical effects clearly dominate the circulation and to express Greenland in differential equations is not easy. Pure theory carried through on simplifying assumptions will certainly contribute much more to our understanding of the physical processes and will direct the attention of the forecaster to the quantities which he must observe, estimate or calculate if he is to make progress but there is a long way to go before he can throw away his synthetic model-making and reduce his problem to computations.

The most fertile line for early practical results, lies, I think, along the extension of established channels, somewhere between pure empiricism and pure theory, what we may call rational empiricism. Theory will tell us what are the essential factors and how they are related but not with adequate precision to provide the best working tools. By co-ordinating experience, not omitting systematic statistical studies, empiricism will continue to fill the gap which theory leaves. In this development the research forecaster, and in his turn the routine forecaster, must, however, be prepared to consider carefully much more than the direct observables and the simple gradients on which he has based most of his methods in the past. There is already sufficient theory to establish the prognostic significance of derived indices, parameters and functions such as vorticity and divergence, geometrical properties of the temperature distribution, stability criteria, circulation indices and so on. Perhaps progress in the early future will come primarily from the systematic introduction of such factors into routine techniques.

The present position is truly exciting. At last we are being provided with data which give us something approaching a factual picture of the behaviour of the atmosphere in three dimensions. The field is open to a comprehensive attack from all sides and the physicists and mathematicians should be on their mettle to extend their claim and to squeeze the empiricist and statistician out of this territory of natural science. Meanwhile forecasting research must look both ways and turn every success to its own advantage.

THE ACCURACY OF A MEAN OF n TEMPERATURE OBSERVATIONS AS AN ESTIMATE OF THE MEAN TEMPERATURE FOR A PARTICULAR MONTH

By N. CARRUTHERS, B.Sc.

Let us consider a month of 31 days and, in the first instance, suppose that the value aimed at is the 31-day temperature mean formed by taking one observation at a fixed hour on each day throughout the month. The goodness of representation of this mean by only n observations (assuming each observation to be on a separate day and at the same fixed hour) depends not only upon the number n but also on how the observations are scattered through the month. On account of persistence, ten observations at three-day intervals will generally give a better estimate of the 31-day mean than will 14 or 15 observations on consecutive days.

The "persistence length" for temperature has been found to be about three days. For scattered days, means of ten or fewer observations will be distributed about the 31-day mean with a standard deviation (σ' say) of $\sigma/\sqrt{n}$, where σ is the standard deviation of single observations about the mean; but, for $n > 10$, the relation between σ' and σ is not quite so simple. The closer n is to 31 the nearer is the n -day mean to the 31-day mean and so the smaller is σ' ; but, at the same time, more of the n values are on consecutive days so that persistence comes into play tending to increase the standard deviation σ' .

A convenient relation for $n \geq N/3$ is given by $\sigma' = \sigma\sqrt{[3(N-n)/(2Nn)]}$ where N is the number of days in the month. This expression is of the correct dimensions in n (i.e. $n^{-1/2}$) and decreases from $\sigma' = \sigma/\sqrt{n}$, when $n = N/3$, to zero when $n = N$.

Where the observations are consecutive, the standard deviation of the n -day means will be $\sigma' = \sigma\sqrt{(3/n)}$ when n is ten or less, because n consecutive observations are equivalent to only $n/3$ independent observations. When n is greater than ten, σ' will lie between $\sigma\sqrt{(3/n)}$ and $\sigma\sqrt{[3(N-n)/2Nn]}$, approaching more nearly the latter expression as n increases.

The n -day means are distributed normally about the 31-day mean. This is true, or nearly so, at all levels in the upper air even although, near the mean height of the tropopause, the distribution of the individual values is not "normal". If therefore d is the amount by which any n -day mean departs from the 31-day mean, we are able to estimate the proportion of occasions on which a given value of $|d|$ is equalled or exceeded by means of tables of the "probability integral". Table I gives related values of λ and P where $\lambda\sigma'$ is the deviation equalled or exceeded on P per cent. of occasions, σ' being given (as above) by the relations (for scattered observations):—

$$\sigma' = \sigma/\sqrt{n}, \quad n \leq N/3 \quad \dots (1)$$

$$\sigma' = \sigma \sqrt{\left\{ \frac{3(N-n)}{2Nn} \right\}}, \quad n \geq N/3 \quad \dots (2)$$

The expressions (1) and (2), with the aid of Table I, enable us when σ is known to compute the minimum number of (scattered) observations required to give an estimate of the mean for the month to any specified degree of accuracy. Suppose that σ is measured in degrees Fahrenheit and an accuracy of $u^\circ\text{F.}$ is required on at least $(100-P)$ per cent. of occasions. To obtain this degree of accuracy we require $\lambda\sigma' \leq u/2$, the value of λ being that corresponding to the chosen value of P in Table I. Using this relation, we find from (1) and (2) after transposing,

$$n \geq 4\lambda^2\sigma^2/u^2 \quad \text{where } \lambda\sigma/u \leq \sqrt{(N/12)} \quad \dots (3)$$

$$n \geq 1/\left\{ \frac{1}{N} + \frac{u^2}{6\lambda^2\sigma^2} \right\} \quad \text{where } \lambda\sigma/u \geq \sqrt{(N/12)} \quad \dots (4)$$

TABLE I—RELATION BETWEEN λ AND P

If the mean of n observations within an N -day month differs by d from the mean of the whole N observations (one each day), and σ' is the standard deviation of n -day means about the N -day mean, then $|d| \geq \lambda\sigma'$ on P per cent. of occasions.

P (per cent.)	1	5	10	20	25	33 $\frac{1}{3}$	50
λ	2.576	1.960	1.645	1.282	1.150	0.976	0.675
P (per cent.)	4.6		13.4		31.7		
λ	2.00		1.50		1.00		

Table II gives average values of standard deviation of temperature at different levels over Larkhill. These were determined by taking the square root of the average of the variances for the four seasons of the year, each variance being that of all observations during the years 1942-44 about the seasonal mean for the whole period. The average value of the standard deviation within a specified month (referred to in this note as σ) is less than the standard deviation for the same level in Table II, probably by about 5 to 10 per cent.

TABLE II—STANDARD DEVIATION OF UPPER AIR TEMPERATURE
(Average seasonal values over Larkhill, 1942-44) *

Pressure level (mb.)	900	700	500	300	250	200	170	150	130	100	80
Standard deviation ($^\circ\text{F.}$)	7.25	8.04	8.40	6.72	7.11	10.94	11.20	10.38	9.11	9.09	9.88

These values are a measure of the variability of temperature observations (during one season of the year) about the long-period mean.

Table III gives, for the range of values of σ likely to occur in the upper air over England, the number of observations n required for a mean, correct to within 5, 2 and 1°F. on 75 per cent. of occasions and to within 5°F. on 66 $\frac{2}{3}$, 75 and 95 per cent. of occasions. These values of n have been computed from the expressions (3) and (4) with the aid of Table I. They are given to a decimal place to facilitate rough interpolation.

Table IV relates n with u and $(100-P)$ in a different way, showing how often an accuracy $u^\circ\text{F.}$ is obtained with specified values of n when $\sigma = 7^\circ\text{F.}$ and when $\sigma = 10^\circ\text{F.}$ In general 6 or 7 observations will give on half the occasions an accuracy of 5°F. but about 20 observations are required for an accuracy of 2°F. , and about 27 for an accuracy of 1°F. on half the occasions.

TABLE III—MINIMUM NUMBER n OF TEMPERATURE OBSERVATIONS WITHIN A 31-DAY MONTH FOR AN ESTIMATE OF THE 31-DAY MEAN

Standard deviation (σ)	Number of observations				
	Correct to 5°F.			Correct to 2°F.	Correct to 1°F.
	66 $\frac{2}{3}$ per cent. correct	75 per cent. correct	95 per cent. correct	75 per cent. correct	75 per cent. correct
°F.					
7.0	7.3	10.3	18.4	21.5	28.7
8.0	9.6	12.3	20.3	23.2	29.2
9.0	11.4	14.0	21.9	24.5	29.6
10.0	13.0	15.7	23.2	25.5	29.8
11.0	14.5	17.1	24.2	26.3	30.0

σ is the standard deviation of single temperature observations within the month and is probably about 90–95 per cent. of the standard deviation referred to a long-period mean.

An examination of actual data over Larkhill was made for a winter and for a summer month chosen at random. Table V shows for January 1942 and July 1947 at 900 and 200 mb. (a) the mean temperature at 1200 and the standard deviation σ within the specified month, (b) means of ten observations at three-day intervals with corresponding values of $|d|/\sigma$, (c) means of ten observations on consecutive days with corresponding values of $|d|/\sigma$. As above, d is the departure of the ten-day mean from the 31-day mean (given in (a)) and $|d|$ denotes the magnitude of d without regard to sign. For ten scattered

TABLE IV—PERCENTAGE NUMBER OF OCCASIONS WHEN A GIVEN ACCURACY ($u^\circ\text{F.}$) IS ATTAINED WITH n OBSERVATIONS OF TEMPERATURE
Number of possible days in month = 31

Standard deviation	Accuracy (u)	Number of observations per month (n)						
		5	10	15	20	25	28	30
°F.	°F.				percentage			
7	1	13	17	25	34	49	68	93
	2	25	35	47	62	81	95	99.96
	5	58	74	88	97	99.91	(100)	(100)
10	1	9	13	17	24	36	51	79
	2	18	25	34	46	65	83	99
	5	42	57	73	88	98	99.95	(100)

observations (b) we expect $|d|/\sigma$ to equal or exceed $\lambda/\sqrt{10}$, and for ten consecutive observations (c) we expect $|d|/\sigma$ to equal or exceed $\lambda(3/10)$ for P per cent. of the values. There are 12 values of $|d|/\sigma$ in (b) and in (c) but each group of three is equivalent to only two independent values and so, to obtain the value equalled or exceeded by the largest $|d|/\sigma$ in (b) or in (c), we take for λ the value corresponding to 1 in 8, i.e. to $P = 12\frac{1}{2}$ per cent. so that $\lambda = 1.52$. Considering the eight largest values in (b) and in (c), we find the following comparison between observed and expected values of $|d|/\sigma$

	$ d /\sigma$ equalling or exceeding							
	(b)				(c)			
	0.21	0.28	0.36	0.48	0.37	0.49	0.63	0.83
number observed	4	3	1	0	4	3	2	0
number expected	4	3	2	1	4	3	2	1

or, taking the mean of each set of three values, viz.:—

(b) 0.16 0.21 0.27 0.08, and (c) 0.23 0.29 0.51 0.39, the comparison for four independent values is

			$ d /\sigma$ equalling or exceeding					
			(b)			(c)		
			0.10	0.21	0.36	0.17	0.37	0.63
number observed	..	..	3	2	0	4	2	0
number expected	..	..	3	2	1	3	2	1

The comparisons are reasonably good when account is taken of the smallness of the numbers of independent values.

TABLE V—MEAN TEMPERATURES AT 1200 G.M.T. OVER LARKHILL

		January 1942		July 1947	
		900 mb.	200 mb.	900 mb.	200 mb.
(a)	Mean of 31 observations (°F.)	28.5	—63.7	52.6	—53.5
	Standard deviation (°F.)	4.88	10.08	6.77	5.14
(b)	Means of 10 scattered observations (°F.)				
	days { 1, 4, 7, . . . 28	29.6	—63.6	53.9	—52.8
	{ 2, 5, 8, . . . 29	28.0	—60.6	49.5	—53.8
	{ 3, 6, 9, . . . 30	27.7	—66.9	53.6	—53.7
	Values of $ d /\sigma$				
	days { 1, 4, 7, . . . 28	0.23	0.01	0.19	0.14
	{ 2, 5, 8, . . . 29	0.10	0.31	0.46	0.06
	{ 3, 6, 9, . . . 30	0.16	0.32	0.15	0.04
(c)	Means of 10 consecutive observations (°F.)				
	days { 1–10	29.5	—67.6	47.0	—52.2
	{ 11–20	27.0	—61.3	53.1	—56.4
	{ 21–30	29.4	—61.4	56.9	—51.7
	Values of $ d /\sigma$				
	days { 1–10	0.20	0.39	0.83	0.25
	{ 11–20	0.31	0.24	0.07	0.56
	{ 21–30	0.18	0.23	0.63	0.35

Different hours of observation.—If the mean temperature aimed at is that found by taking observations at h different hours on each of the N days of an N -day month, the values of σ' (standard deviation of means of n observations) considered above will have to be increased to allow for variation of temperature during the day. Means based on one observation per day (all N days of the month), at different times of day, will have a standard deviation about the required mean (comprising hN observations) of σ_h , say, where

$$\sigma_h = \frac{1}{h} \sum_{r=1}^h M_r^2 - \left[\sum_{r=1}^h M_r \right]^2, \quad \dots (5)$$

M_r being the mean temperature, for the specified month, at the r th observation hour. We then have, for the standard deviation of means of n observations scattered through the month, and at divers hours,

$$\sigma' = \sqrt{\left[\frac{\sigma^2}{n} + \sigma_h^2 \right]} \quad \text{for } n \leq N/3 \quad \dots (6)$$

$$\sigma' = \sqrt{\left[\frac{3(N-n)}{2Nn} \sigma^2 + \sigma_h^2 \right]} \quad \text{for } n \geq N/3 \quad \dots (7)$$

At most levels in the upper air over Larkhill σ_h is small compared with σ .

METEOROLOGICAL OFFICE DISCUSSION

Rocket-sondes

The Discussion, held at the Imperial College on November 29, 1948, was on the high-altitude research work with V-2 rockets carried out in New Mexico by the U.S. Naval Research Laboratory. Mr. D. D. Clark opened the discussion which was based on the following five papers:—

Krause, E. H.—High-altitude research with V-2 rockets. *Proc. Amer. phil. Soc., Philadelphia, Pa.*, **91**, 1947, p. 430.

United States Naval Research Laboratory. Upper atmosphere research reports :—

I.—*U.S. naval Res. Lab. Rep.*, No. R-2955, 1946.

II.—*U.S. naval Res. Lab. Rep.*, No. R-3030, 1946, by H. E. Newell and J. W. Siry.

III.—*U.S. naval Res. Lab. Rep.*, No. R-3120, 1947.

IV.—*U.S. naval Res. Lab. Rep.*, No. R-3171, 1947.

Towards the end of 1945 the American Naval Research Laboratories began investigating the possibilities of the rocket-sonde. At the time the only suitable rocket available was the German V2 of which there were adequate supplies. As tests on these rockets were due to begin at the ballistics and ordnance testing ground at White Sands, New Mexico, in a few months' time, the opportunity was taken to combine these trials with the upper atmospheric research programme. In this way a delay of two to three years, pending the development of a suitable rocket, was avoided and experiments were able to begin almost at once.

The first trials were due to start three months after the formation of the rocket-sonde section, which meant that, with the limited time for preparation, much improvization was necessary. Firings took place about once every fortnight according to a programme arranged to expend all the stock of rockets before deterioration rendered them unserviceable. It was expected that development of the instruments and technique would take up most of the first year; however, progress was better than expected and results were obtained in many fields. Besides the Naval Research Laboratories other institutions took part in the experiments, including the Universities of Michigan, Princeton, Harvard, the Johns Hopkins University, the National Bureau of Standards and the Californian Institute of Technology.

Investigations covered the fields of solar spectroscopy, cosmic radiation, the ionosphere, and the pressure and temperature of the atmosphere. In solar spectroscopy interest centred on the absorptive properties of the atmosphere, including the ozone distribution, and on the intensity and nature of the solar ultra-violet radiation. From the study of cosmic radiation it was hoped to obtain first-hand knowledge of the primary particles as they enter the atmosphere. The ionosphere experiments were expected to furnish information on the ion density at intermediate points between the ionised layers and the measurement of pressure and temperature would give data which could be compared with existing knowledge.

Special instruments had to be developed to operate at the very low pressures and under conditions of vibration and acceleration occurring during the rocket's flight. The maximum height reached would be in the neighbourhood of 150 Km.

but the part of this flight during which observations were to be made lasted only some five minutes during which time the rocket was travelling at anything up to one mile a second. After the arrangements for taking the observations had been made there still remained the problem of recovering the data.

The V2 is 46 ft. long and $5\frac{1}{2}$ ft. in diameter, it weights 28,000 lb. with fuel, 9,000 lb. empty, and has a pay load of 2,000 lb. For the experiments the former warhead was replaced by a new type specially designed to house the instruments. It normally contained various pressure and temperature gauges, the cosmic-ray counters and the electronic gear, which was housed in a pressurised case, also batteries and some ground controls. Behind the warhead is the control chamber in which are installed the control units for the rocket and the Doppler tracking equipment. The main body houses the fuel tanks, the pumps, and the motor. Three carbon vanes in the jet of exhaust gases from the motor stabilise the rocket during powered flight but when the fuel is exhausted the rocket may roll and yaw.

Aerials for the ionosphere experiments were attached to the tail and trailed behind during flight. Others were attached delta-wise to the rocket body and two tail fins. Occasional fading of the signals was experienced due to masking of the aerials by the exhaust jet or the rocket body.

The tail fin was chosen as the best site for the spectrograph, and cameras were mounted at mid points on the body to record the changes in orientation during flight.

The position and velocity of the rocket, which must be accurately known if the other observations are to be of any use, is obtained by Doppler tracking methods, by radar, and by optical telescopic theodolites. Of these the Doppler method and the theodolites were the most successful.

Two methods were used to recover records: telemetering to the ground and physical recovery of the recorded data after the flight. In the telemetering system the instruments are designed to present the observations in the form of representative voltages in the range 0-5 v. which are applied to control a pulse-emitting circuit so that the spacing between successive pulses is proportional to the applied voltage, thus producing a pulse time-modulated transmission. These signals are received at the ground station, where they are re-converted into characteristic voltages which are recorded photographically on an oscillograph. The arrangement is such that a measurement is made and recorded for every 8 m. of flight path. The accuracy expected was ± 5 per cent. which was later improved to ± 1 per cent. The frequency of the 3 Kw. transmitter was chosen at 7,000 Mc./sec. to be high enough to penetrate the ionosphere and also to be clear of other frequencies in use.

The second method of recovery meant installing an automatically recording instrument which could stand up to vibration and accelerations of 6g, and afterwards endeavour to recover the record after the flight. Recording in nearly all cases was performed photographically, the films being wound into steel containers after exposure. Unless the record is separated from the rocket before impact there is little hope of recovering anything. Separation was attempted using ejection mechanisms but most success was obtained by simply exploding the rocket, during its descent, into three pieces, the warhead, the main body and the tail section. The automatically recording instruments

which had been mounted in well-protected positions in their respective sections were then recovered in good condition.

Pressure measurements covered the range from 10^3 to 10^{-4} mm. of mercury which necessitated the use of several different types of instrument. The range from 10^3 to 10 mm. was covered by an ordinary bellows type of pressure gauge while, for lower pressures, gauges normally used in high-vacuum work were employed. The bellows gauge was one of the few instruments which incorporated a lever mechanism, the axis of the lever being mounted parallel to the axis of the rocket to avoid effects due to acceleration. A waxed thread from this lever was wrapped round the shaft of a micro-torque potentiometer thus converting movements of the bellows into rotations of the shaft and hence into representative voltages.

The pressure range from 10 to 10^{-3} mm. was covered by Pirani gauges which consist of a filament of fine platinum or tungsten wire heated to about 200°C . by an electric current. At low pressures when the mean free path of the air molecules is comparable with the diameter of the filament, the thermal conductivity of the air is related to its pressure by the approximate formula $K = ap$ where K = thermal conductivity, p = pressure, a = a constant. If the current is kept constant then the temperature, and hence the resistance of the filament, vary with the pressure. This resistance variation is easily converted to a voltage variation. Two types of Pirani gauge were in use. A platinum filament of 0.007-in. diameter was used in the range 10 mm. to 0.1 mm. while a tungsten filament of 0.005-in. diameter was used for pressures from 10^{-1} mm. to 10^{-3} mm. With the platinum gauge the voltage variation over the range was 1 v. at 10 mm. to 3 v. at 0.1 mm. and with the tungsten filament the range was from 2.7 v. at 0.5 mm. to 5 v. at 0.01 mm. These voltages were fed through the commutator directly to the input of the telemetering system.

In the range of pressures from 10^{-2} to 10^{-5} mm. ionization gauges were used. In these gauges, electrons from a heated filament are accelerated towards a collecting electrode. The positive ions formed during their passage are collected on a third electrode. The resulting ion current varies with the pressure, the relationship being linear if the emission is less than 5 milliamps up to pressures of 10^{-3} mm.

A special type of ionization gauge was used in the V2 experiments, called the Philips gauge. In it the electron path is increased several hundred times by a magnetic field across the tube which causes the electrons to move in spirals. The resulting increased electron path increases the probability of electrons ionising molecules which gives a greatly magnified ionization current. With ionization gauges pressures are recorded instantaneously.

The point of the rocket is in the form of a cone, and pressure measurements are taken at the apex of the cone, on the sides of the cone and also at points on a circumference of the rocket near the tail section. The pressure of the surrounding air is derived from the pressure at the tip for heights up to 80 Km., by the application of the theory of planar shock waves as in the case of the pitot tube, but instead of the unknown being the velocity, it is the outside pressure. When pressure is measured on the sides of the cone then Taylor and Maccoll's theory of conical shock waves is resorted to in order to express the pressure in terms of the Mach number or, since the velocity is presumed known, in terms

of the absolute temperature. Another relationship is then sought between the pressure and Mach number (or absolute temperature) such as, for example, an empirical relationship from the wind-tunnel data on the V2, and the two equations then solved simultaneously for pressure and temperature. The outside pressure was also measured directly by making use of a particular property of the V2 as revealed by German wind-tunnel tests, namely that at a circumference on the body just in front of the tail section the pressure reads to within 10 per cent. of the surrounding air pressure and is insensitive to changes in attitude of the rocket. Although the wind-tunnel data referred to Mach numbers up to 2, it was assumed that this relationship held for higher Mach numbers as well. Two Pirani gauges mounted one on each side of the rocket in this position agreed within experimental error throughout the flight which showed that at higher Mach numbers the effect of yaw is still negligible. Pressure readings obtained in this manner were found to agree with those obtained from a radio-sonde ascent made at the same time and place except at the point where the rocket speed was about equal to the velocity of sound.

Above altitudes of 80 Km. the mean free path of the molecules begins to assume the dimensions of the rocket, while above 100 Km. the mean free path is much greater than the rocket's dimensions. In the region above 100 Km. the problem is treated statistically, and, by means of the Maxwell-Boltzmann distribution, a relationship is established between the pressure and temperature at the tip of the cone and the pressure and temperature of the atmosphere. An additional similar relationship is then derived for the pressure and temperature on the side of the cone. The pressure and temperature of the atmosphere at that point of the flight path is then obtained by solving these two simultaneous equations. No method is suggested for obtaining the pressure and the temperature in the region between 80 and 100 Km.

Temperature measurements are made at various points under and on the surface of the rocket for assessing the performance and finding the operating temperatures of the instruments. The gauges utilised were either platinum resistances, ceramic semi-conductors (thermistors) or else thermocouples, the output voltages from which were fed directly to the input of the telemetering set. Atmospheric temperature is either derived indirectly, with the pressure as indicated above, or else is calculated, up to 80 Km., from the slope of the pressure-altitude graph. Since the temperature is a derived quantity depending on measurements of velocity and pressure and the solution of certain approximate relationships, the degree of accuracy is not high and for one flight for which the probable error had been assessed it was given as $\pm 25^{\circ}\text{C.}$ from 50 to 60 Km., $\pm 15^{\circ}\text{C.}$ from 65 to 70 Km., $\pm 20^{\circ}\text{C.}$ at 72.5 Km. and $\pm 40^{\circ}\text{C.}$ above 100 Km. The general shape of the temperature-altitude graph agreed with that predicted by the National Advisory Council for Aeronautics from data already available from other sources. The accuracy of the observations in the troposphere agreed well with those obtained from a radio-sonde ascent. The main features of the temperature at high altitudes were the maximum of about 320°A. at 50 Km., the minimum of approximately 200°A. at 80 Km., and the steady rise above 100 Km. Other methods of direct measurement of temperature have been suggested and some have been tried but, up to the time of writing these reports no successful results had been obtained. The methods suggested included the detonation of explosives ejected from the rocket at

intervals of 10,000 ft. so that by measurements of the time lag between the visual puffs and the sounds of the explosions as measured at a point on the ground, the mean temperature between the 10,000 ft. levels would be found. Another ingenious suggestion was to eject grenades containing small pellets, which would explode, scattering the pellets, some of which should possess sufficient velocity to appear as artificial meteorites which could then be observed with cameras from the ground, and the air density and temperature deduced.

The spectral distribution of solar intensity at the earth's surface depends on the radiative characteristics of the sun and on the transmissive properties of the Earth's atmosphere. Owing to strong absorption by ozone and oxygen molecules, all the wave-lengths below 2900Å are absent at the earth's surface and so the distribution in the ultra-violet is not completely known. To obtain measurements in the range 1100 to 2900Å a height of 90 Km. has to be passed. The spectrograph used in these experiments employed some novel features. To avoid absorption of the ultra-violet rays no lens systems were used; instead, two lithium-fluoride beads having a wide angle of view, and replacing the conventional slit, were situated on opposite sides of the instrument. The beads, which passed all wave-lengths above 1100Å, gave about 100 times more illumination at maximum than a slit and because of their wide angle of view and the alignment of the optical axes, recording was continuous no matter what the orientation of the rocket. The images of the sun from the two beads are reflected on to a concave mirror of 40-cm. radius of curvature on which a grating of 15,000 lines to the inch is engraved. The spectra from the two images are focused side by side on to a 35-mm. film which is wound by a small electric motor. Owing to astigmatism of the grating the point image of the sun produces a line spectrum on the film. Separate exposures are made, the shutters consisting of sector disks (one for each bead) which rotate continuously at constant speed behind the beads. Each time an exposure is made the film is arrested and a signal is transmitted to the ground station so that each photograph may be identified later. The film is finally wound into an armoured container where it is preserved until recovered after the flight. To photograph radiation of less than 2200Å, which is absorbed in gelatine emulsions, the emulsion on the film is coated with material which absorbs ultra-violet light and fluoresces in visible and near ultra-violet radiation (any oil film will do this). With the aid of this spectrograph the curve of average radiant energy as a function of wave-lengths was extended from 2900 to 2200Å. It was found that the ultra-violet intensity is much less than was predicted. A large number of fully and partly resolved absorption minima were observed between 2950 and 2300Å, nearly all of which were blends of two or more closely spaced lines. The analysis of the line widths and intensities which are important in determining the excitation conditions in the sun is not yet complete.

The ozone distribution between two levels in the atmosphere is derived from comparison of the spectra at these two levels. The results generally confirm observations made by other methods. On one particular occasion, for example, maximum concentrations were found at 17 Km. and at 25 Km. Above 30 Km. the concentration decreased rapidly and vanished within experimental error at 50 Km. A graphical integration gave the total concentration as 2.7 mm. at standard temperature and pressure which agreed with other observations taken just before and just after the flight of 2.5 and 2.7 mm. respectively.

Methods at present in use to determine the ion density in the ionosphere give only the maximum values for each layer. It was hoped that with the rocket-sonde, direct measurements of the ion density at all points would be possible. Two radio frequencies were chosen, one of which was near to the critical ionospheric frequency for that day and the other an integral multiple of this frequency. The lower frequency signal will be retarded by the ionised layers while the higher frequency will be unaffected. If the two frequencies are emitted simultaneously from the rocket and received at the ground station, then, if the lower frequency is multiplied by the integral quotient of the two and compared with the other it will be found that passage through the layers of the ionosphere has resulted in a phase shift between the two. After making the required corrections for Doppler effect and instrumental changes it was hoped to be able to deduce the ion density at all points of the flight path. At the time of writing the reports, the analysis, which is very complex, had not been completed.

A considerable number of the experiments were taken up with cosmic radiation investigations with a view to determining both the nature of the primary radiation and to studying the fundamental reactions which take place as the primaries pass through the atmosphere. Geiger-Müller counters were employed to detect the rays owing to the ease with which the counts could be telemetered. Absorption tests were made with lead thicknesses of 2, 4, 6, 12 and 14 cm. It was found that 35 per cent. of the rays were stopped in the first 4 cm. of lead; therefore, at least this portion was not primary. It was suggested that these were electrons which arose from the atmosphere below due to meson decay and spiralled round the Earth's magnetic field lines. The remaining 65 per cent. penetrated 4 cm. of lead, some producing showers. From the percentage penetrations of the other thicknesses of lead it was deduced that if all the radiation penetrating 6 cm. was primary then the electron component, on the basis of shower production, was not more than a maximum of 14 per cent. of the primary, while the non-electronic component penetrating 12 cm. was 68 per cent. of the primary and that absorbed in 12 cm. was 18 per cent. of the primary. Also the ratio of total radiation in free space to that at sea level was 11.5 : 1 while the ratio of the hard component in free space to that at sea level was 9 : 1.

In addition to measurements recorded and telemetered, interesting photographs of the Earth have been taken from the rocket at high altitudes. The experiments with rocket-sondes are still in progress, other types of rocket have been developed and are now in use, the instruments and methods described above are being constantly modified and improved upon. What is encouraging is that in all the fields which were investigated results of greater or less importance have been achieved. Although the importance of the rocket-sonde in investigation in the upper atmosphere is recognised it is still a research instrument whose present high cost of operation will confine its use to investigations of a special character for many years to come.

The Director, in opening the discussion, said that the effort and industry put into these trials is to be admired as well as the way in which methods and instruments usually associated with the research laboratory have been adapted and employed in these experiments. The photographic results have been good and the temperature results for the upper atmosphere are very interesting. He asked the following questions:—

Has anyone any explanation of the double maximum in the ozone distribution curve ?

Has the upper minimum in the temperature curve ever been repeated ?

How were the estimates of the errors in the temperature readings obtained ?

Is there any information on air density or composition of the air ?

Dr. Harrison thought that one possible explanation of the double maximum in the ozone distribution is that ozone having a higher molecular weight than oxygen may tend to diffuse downwards. It has been suggested that ozone affects the performance of radio-sonde balloons. He asked:—

Why was the radar tracking found to be unsuccessful ?

Is the null point of the pressure from the wind-tunnel experiments dependent on the air density and, if so, what result would that have on the measurements ?

Mr. Absalom said more temperature observations were required both by day and by night. The shape of the temperature-height curve is systematic; low temperatures of 100°A. at 80 Km. have been reported in a paper by Seaton.* According to Regener the fundamental layer in the ozone distribution is the upper maximum, the lower layer being caused by transport of ozone from lower latitudes.

Dr. Robinson said that in his recent paper* Seaton claimed that differences in temperature at 100 Km. of 500°A. between 40° and 20° latitude occurred at the same time. The null point method of pressure measurement on the rockets is not very satisfactory. Was the temperature-height curve from the rocket data based on more than one ascent ?

Have temperatures been taken at night ?

Has any laboratory work been done on the wind-tunnel tests of shock wave theory for low pressures ?

Professor Stratton asked if the attempt to produce artificial meteorites met with any success.

Mr. Weeks said the measurement of ion density by the phase-shift method does not take into account the effect of the Earth's magnetic field and the polarization of the emitted rays.

Dr. Scrase asked if any attempt had been made to take samples of the atmosphere and, if so, how was it done ?

Cdr. Frankcom said the ocean weather ships regularly take observations on meteors; would it be possible to observe artificial meteor showers from ships and would it be of any use ?

Mr. Ashford pointed out that Pirani gauges have a time constant which would be important on a rocket travelling at high speed. Are there any figures on the lag of the Pirani gauges used in these experiments ?

Is the gap in temperature and pressure data between 80 and 100 Km. due only to the lack of a suitable method of extraction or were observations not taken over this interval as well ?

How many measurements can be made in one ascent ?

*SEATON, S. L.; State of the upper atmosphere. *J. Met. Lancaster, Pa.* 5, 1948, p. 204. [In this paper Seaton calculates temperature from radio observation of the rate of recombination of the ions.—Ed. M.M.]

Mr. G. Oddie asked has it ever been tried to launch the recording equipment from the rocket at the top of its flight and let it descend by parachute? The very high impact speeds of the rocket would then be avoided.

Mr. Clark stated in reply that the diffusion theory was probably correct in the explanation of the double maximum in the ozone layer. Double maxima had been found before by Götz. The ozone was formed in the upper layers, probably at 50 Km., and so the presence of the second maximum must be explained by either diffusion or transport from other latitudes. The rate of formation and dissociation of the ozone may also come in.

The temperature figures given referred to one particular ascent; it was not known if the second minimum in the temperature curve had been repeated in later flights but the presence of that minimum is generally accepted and is given in the latest estimate of upper atmospheric temperatures published by the National Advisory Committee of Aeronautics, Washington, D.C. It has also been confirmed by Fred Whipple's work on meteors and is given by some authors as the explanation of the existence of noctilucent clouds observed at this altitude. The estimates of the errors in temperature have not been given in detail in the reports but it can be assumed that they were based on the sum of the instrumental and electronic errors of all the measurements required for their determination.

No attempts were made to measure air density directly. Some attempts were to be made to take samples of the air to investigate the composition of the atmosphere.

The failure of the radar method of tracking is not made clear in the reports.

The null point method of obtaining the pressure was based on wind-tunnel experiments made in Germany. So far as is known these tests were not extended to cover low densities, so that the use of this method in the rocket-sonde experiments is based on the assumption that this relationship holds also at low densities.

No successful ascents had been made at night up to the date of writing the reports nor is there any mention in the reports of any laboratory confirmation of the shock-wave theories for low pressures. As regards the artificial meteors, grenades have been launched successfully and exploded but the fragments have not so far been observed.

A method for taking samples has been mentioned and has no doubt since been tried. A long-necked bottle which has been evacuated is opened at high altitude by breaking the neck and then resealed by compressing and soldering a metal part of the neck.

The Pirani gauges used had a lag of 1.5 sec. which is equivalent to 2-Km. path length at 60-80 Km. The data incorporate this correction.

Observations were made continuously; the gap from 80-100 Km. is no doubt due to the lack of a reliable method of extraction.

Measurements can be made and transmitted at 200 a second; the total number depends on the length of the flight subject to instrumental failure.

No attempts have been made to launch the equipment from the rocket on a parachute apart from recovery trials.

ERRATUM

January 1949, PAGE 20, last line ; *after* 400 mb. *add* and -16°F. at 200 mb.

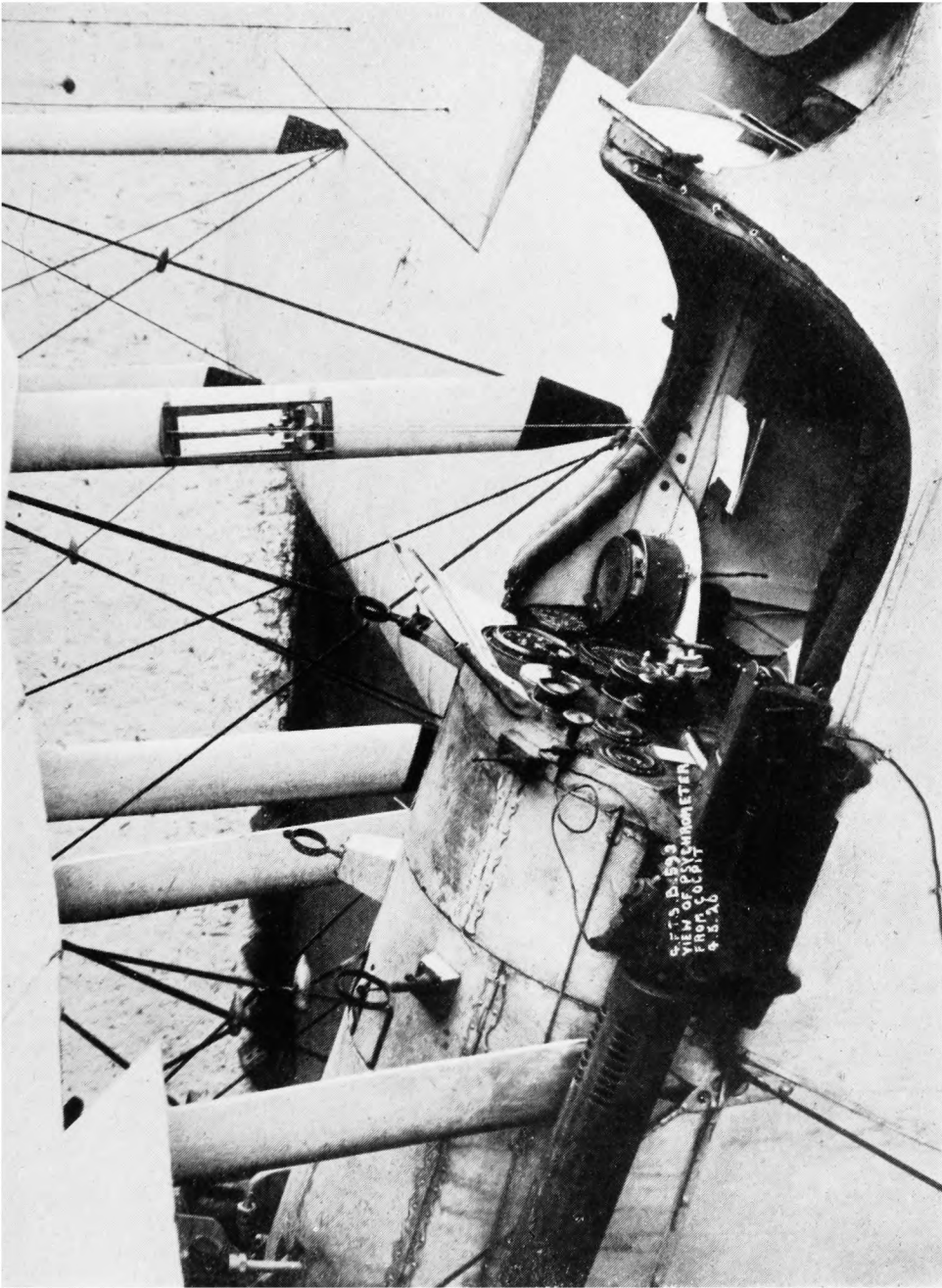


FIG. 1.—STRUT PSYCHROMETER MOUNTED ON AN AIRCRAFT IN 1926

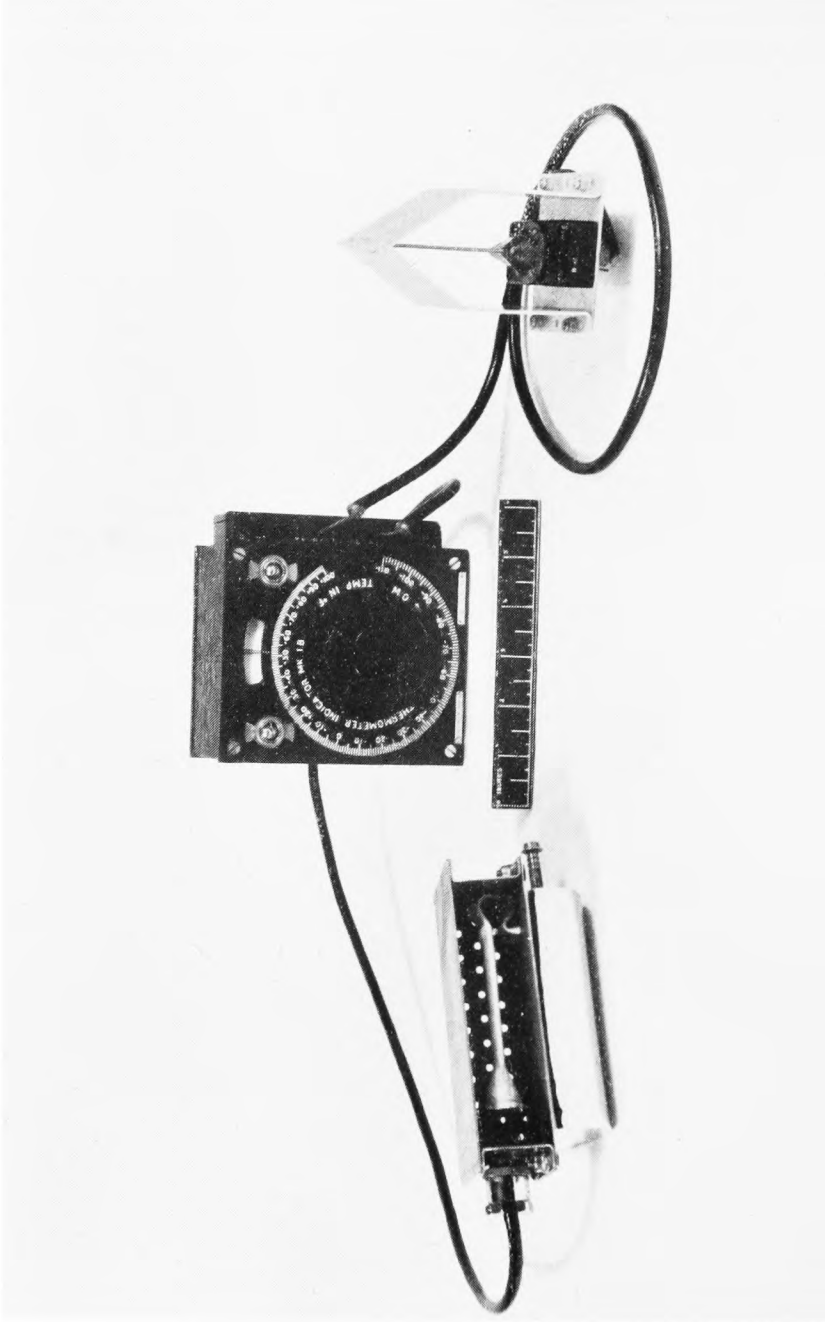


FIG. 2—ELECTRICAL RESISTANCE THERMOMETER
(see p. 84)



FIG. 3—ELECTRICAL RESISTANCE THERMOMETER MOUNTED ON A BOSTON
(see p. 84)

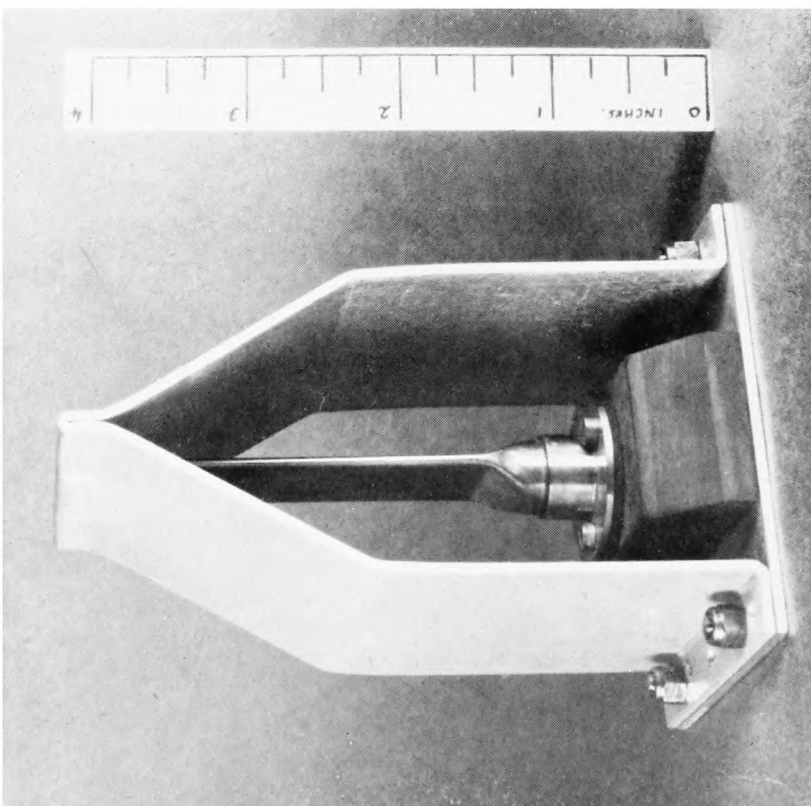


FIG. 4--DRY BULB OF THE ELECTRICAL-RESISTANCE
THERMOMETER

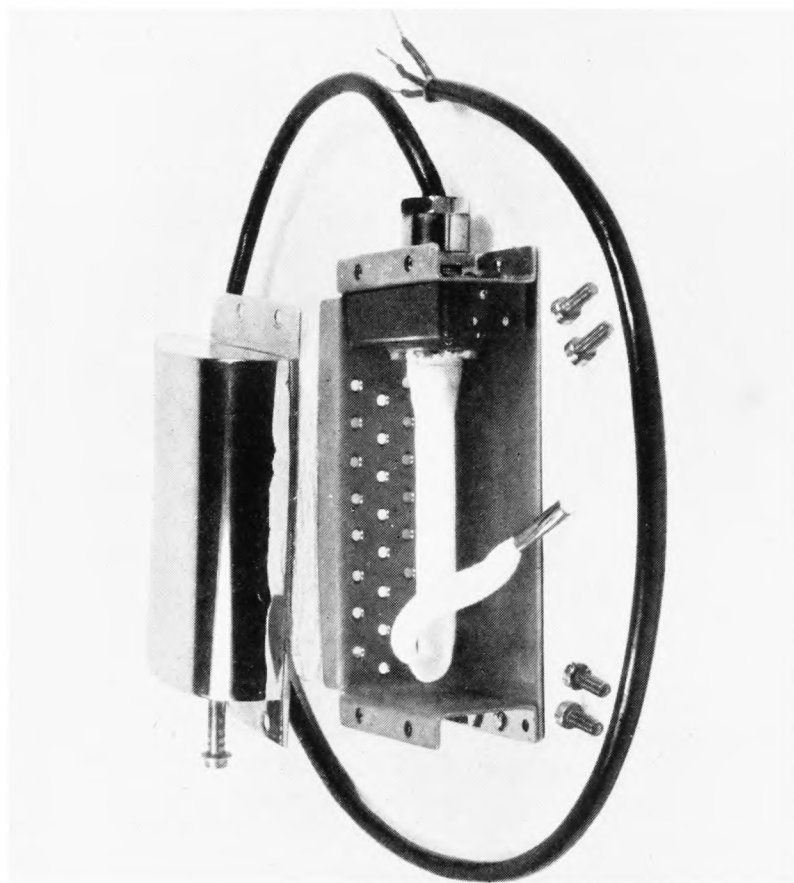


FIG. 5--WET BULB OF THE ELECTRICAL-RESISTANCE
THERMOMETER

METEOROLOGICAL RESEARCH COMMITTEE

The fourth meeting of the Instruments Sub-Committee was held on January 20, 1949. The Committee considered reports on the application of the chronometric principle to radio-sondes and decided to pursue alternative lines of development. The future lines of development of measurement of upper winds by radar methods were also discussed and a general policy agreed. The instrumental part of the research programme was reviewed and recommendations for changes were formulated.

The fourth meeting of the Synoptic and Dynamical Sub-Committee was held on January 27, 1949, the business of the Committee being mainly concerned with proposals for the amendment of the Research Programme. A paper by Dr. A. H. R. Goldie, "Measure of atmospheric circulations" (*Met. Res. Publ.*, No. 428), was also considered.

The fifth meeting of the Physical Sub-Committee was held on February 3. The primary business of the meeting was consideration of amendments to the appropriate part of the research programme. A paper, *Met. Res. Publ.* No. 452, on the size distribution of raindrops was also considered.

OFFICIAL PUBLICATIONS

The following publication has recently been issued:—

Instructions for the preparation of weather maps, with tables of the specifications and symbols

This publication contains instructions for decoding and plotting weather messages giving surface observations from land stations and ships. The instructions are based on the system of plotting adopted at the International Meteorological Conference at Warsaw in September 1935, with such amendments as are necessitated by the introduction of the new codes approved by the Conference of Directors at Washington in September 1947.

The illustrations and tables include reproductions of all the symbols used for plotting station and ship reports, fronts and weather areas, together with specimen plottings. The relevant symbolic forms of codes and tables of specifications (reproduced from the "Handbook of weather messages, codes and specifications", Parts II and III) are given in an Appendix. The publication thus provides, in concise form, all the information required for plotting surface charts, according to the practice of the Meteorological Office.

ROYAL METEOROLOGICAL SOCIETY

Discussion on post-glacial climatic change

At the joint meeting of the Society with the Royal Astronomical Society held at the Science Museum on December 15, 1948, a discussion took place on post-glacial climatic change.

The discussion was opened by Mr. Hoyle who considered the possibility of variations in solar radiation, Dr. H. Godwin of the British Ecological Society who outlined the biological evidence of climatic change, Professor Manley

speaking on fluctuations of climate shown by instrumental and other records in the past 200 years, and by Dr. C. E. P. Brooks who gave a comparison of the evidence from numerous sources with a general discussion on the meteorological aspects.

Mr. Hoyle, pointing out that the earth's mean temperature depends upon its distance from the sun and the sun's radiation, said that, according to astronomical theory, if the sun were left to itself it would very slowly increase in brightness while there was no evidence of any significant change in the distance of the earth from the sun in the last 10 million years.

However, the sun was not left to itself because there was a very great deal of interstellar gas aggregated locally into "clouds". As the sun passed through a cloud it would capture some of the gas which would have the effect of appreciably increasing its ultra-violet radiation. This theory, due to Hoyle and Lyttleton, had been recently confirmed by observations of the spectra of dwarf stars in regions known to contain the necessary "clouds". The solar ultra-violet radiation is absorbed in the upper layers of the atmosphere and Mr. Hoyle suggested that a substantial increase in its intensity, such as would occur when the sun passes through a cloud of interstellar gas, would produce a profound disturbance in the state of the atmosphere which might well be connected with the long-period changes in climate over millions of years.

Dr. Godwin said much of the biological evidence for climate change was based on the analysis of tree pollen. He gave diagrams showing the densities of pollen of various trees, from the warmth-loving lime to the birch which preferred a cold environment, found in the deposits in Hockham Mere, Norfolk. These deposits showed the late glacial tundra, the well-known Atlantic warm period from 6000 to 3000 B.C. and the cold wet period which set in suddenly about 500 B.C.*

Dr. Godwin went on to point out that though biologists must supply much of the evidence for climatic change they are not sure to what extent species are in equilibrium with the climate. In this connexion he described the interesting work of Iversen† on the climatic control of the development of the mistletoe, holly and ivy. This worker plotted on scatter diagrams, having the mean temperature of the warmest and coldest month as ordinate and abscissa, the state of development reached by these three plants at a number of meteorological stations in Europe. On these scatter diagrams called "thermospheres" it was possible to draw curves delimiting temperature régimes in which the plants were able to reach various stages of development (grew but no flowers, flowered, etc.).

It was satisfactory to note that similar curves plotted from pollen analysis of deposits at a station in Denmark gave past temperature régimes agreeing with other evidence.

Professor Manley opened his remarks by pointing out that the instrumental long-period records, those for temperature in north-west Europe are available from A.D. 1706, may give the key to past changes. The accordance between trends shown by the recently reduced Swedish, Dutch and British records is sufficient to lead to a certain confidence on the results they show. These can

*see BROOKS, C. E. P.; Unsolved problem of climatic change. *Met. Mag., London*, 76, 1947, 128.

†IVERSEN, J.; *Viscum, hederia and ilex as climate indicators. Geol. Fören. Stockholm Forh.*, 66, 1944, p. 463.

be related to behaviour of Scandinavian and Icelandic glaciers, which vary primarily with temperature, and their greatest post-glacial advance culminated about 1750 (sometimes 1850); since when retreat has prevailed. In north England and Sweden the last 100 years have seen an appreciable overall rise in winter temperature; summers bring little changes. Ångström has interpreted this as due to "increased vigour of the circulation". It is still uncertain whether this is world-wide and whether an extra-terrestrial agency must be invoked.

This "little ice age" culminating about 1750 apparently began in Iceland with a deterioration about 1300, similar in character to that of 500 B.C. referred to by Dr. Godwin. Adopting as a working hypothesis that the prevailing vigour of the circulation changes rather rapidly from time to time both the above deteriorations may be explained as due to increased vigour accompanied by a spread of the Arctic ice and its melt water. Whereas the present-day amelioration is also associated with increased vigour but a decrease in the extent of the sea ice. This and other data suggest that if this working hypothesis is used the spread of the sea ice must be regarded as an independent variable, dependent on other factors which he hoped the oceanographers would elucidate.

If glacier variation depends so largely on the length of the ablation season it should be closely associated with variations of spring temperature; if these are put in 10-yr. running means the results are certainly agreeable and point again to the probable effect of the spread of Arctic sea-ice on the temperature of polar maritime air. Instrumental records suggest that tropical maritime air in winter has had much the same temperature throughout.

Earlier variations in summer mean temperatures required by Iversen for Denmark, and also those shown by the late glacial Alleröd oscillation, are of the same dimensions as those shown by the decadal values of the present record. The vigour of the circulation hypothesis is capable of satisfying them all, while the spread of the melt water governs the "pitch" (50°F. Alleröd, 60°F. today), around which oscillations occur. Perhaps we should explore further to see why this "vigour" should be changes not merely for a decade, but for several centuries; and what relationship if any this all bears to solar radiation. Possibly this is another aspect of the warm anticyclone problem.

Dr. Brooks showed a composite diagram which was more qualitative than quantitative and which included all the data that he could get hold of. The period about 6000 B.C. to 3000 B.C. after being decidedly cold and ameliorating with cold winters and hot summers was warm—the climatic optimum; such a period could be explained astronomically, by a greater tilting of the earth's axis, for instance. Also the Baltic Sea would be more open after about 4000 B.C. so that in north-west Europe (on which the data were based) one had to consider a compromise between solar radiation and lower sea level.

However, the same climatic change seemed to occur over the whole of the northern hemisphere which could only be explained terrestrially by Arctic-ice conditions. Arctic ice does not explain the climatic optimum which must therefore depend upon solar radiation.

Dr. Brooks had reproduced a number of curves of sunspot frequency, thunderstorm frequency, auroral frequency, rainfall in south Russia (based on mud thicknesses in a small lake), and tree-ring thicknesses (of sequoias in California). He showed that there was some agreement between them but it

was not very good. The rainfall curve showed a maximum about the time of the climatic optimum which must therefore be a period of increased solar radiation. From about 1000 B.C. Dr. Brooks showed that the temperature was decreasing as the rainfall increased; he thought that Petterssen's explanation—the changes being due to changes in tidal force—quite good. More warm water in the arctic would mean a wet period in the northern hemisphere which would tend to break the ice cap. This drifting south would cause stormy conditions; as the ice retreats the summer would be dry as in 1921.

In conclusion Dr. Brooks thought the shorter variations (periods of the order of a century) could be explained by solar-radiation changes. Very short changes of the order of a decade were, in his opinion, due to nothing at all; he had plotted overlapping means from random numbers and obtained curves precisely similar to the 20-yr. moving means of temperatures in London. We should not therefore attempt to explain the small-period variations.

During the discussion which followed the following points were raised:—

Could Hoyle's theory explain short-period variations? Mr. Hoyle said it could if there were local variations in the gas clouds. The biological evidence might be affected by widespread plant disease. The sea-bottom sediment cores recently obtained should be analysed for evidence of climatic change. Mr. Schove explained the possibilities of using the written records of China which go back to 500 B.C. as given in his article in this magazine.*

ROYAL GEOGRAPHICAL SOCIETY

On January 24, Professor C. G. Rossby, Professor of Meteorology in the Universities of Chicago and Stockholm, lectured to the Royal Geographical Society on "Circulation patterns of the free atmosphere; their geographic and climatic implications".

Professor Rossby opened his lecture by stating that Professor Willett of Massachusetts Institute of Technology had shown in a report, to be published shortly, that both the long-term climatic variations in post-glacial times and short-term fluctuations in weather are associated with a contraction or expansion of the circumpolar vortex. Contraction of the vortex gives strong westerly winds and positive temperature deviations while expansion gives a weak westerly circulation, negative temperature deviations, greater frequency of north and south winds.

Rossby said his own connexion with the subject dated from 1936, when he was asked by the U.S. Department of Agriculture to investigate the meteorology of the droughts of 1934-36, and in this investigation he had to get rid of the small perturbations and try to get at the controlling factors deciding what tracks should be followed by the rain-bearing disturbances. This had been done by drawing mean surface-pressure charts for 5- or 7-day periods which were classified as high circulation-index pattern corresponding to Willett's contracting vortex and low index corresponding to the expanding vortex.

With the much increased upper air information available during and since the war, it became possible to construct charts of flow in the free atmosphere, which gave a hydrodynamic smoothing of the perturbations, as distinct from the statistical smoothing of the mean surface-pressure charts. These free-atmo-

**Met. Mag., London*, 178, 1949, p. 11.

sphere charts, mostly contours of the 500-mb. surface, showed the existence of large wave-shaped patterns in the upper flow superimposed on the general westerly circulation. The waves of these patterns were much longer than frontal "waves". A slide of the chart for October 9, 1945, showed 5 waves and the one for October 19, 1945, 3 waves. A feature emphasised on these charts by Professor Rossby, was the marked tendency for crowding together of the contour lines along a belt with an open pattern to north and south. The chart for January 10, 1947, shown next, gave also the isotherms on the 500-mb. surface showing that these were concentrated along the same belt as the concentration of contours. Next was shown a cross-section of the atmosphere from Thule (north Greenland) to Havana on the same day, in which the concentration of westerly wind along a narrow belt was well marked. In the concentrated flow—the "jet stream"—the speed was 90 m./sec. with a rapid decrease in speed to north and south. Professor Rossby said he had recently read a discussion between air navigators and meteorologists in which no reference had been made to this most important problem of the location of jet streams which, with velocities which might reach 150 m./sec., were of the utmost importance in air navigation, as the U.S. Air Force had found in bombing Japan after flying from the Marianas at 30,000 ft. The earlier view had been that the westerly flow was roughly linear in latitude, but it was clear from these charts that that was by no means the case.

Returning to the steering of surface disturbances by upper flow patterns, Professor Rossby showed the mean 500-mb. contour chart for February 6–12, 1948, with a chart of the tracks traversed by the surface disturbances, which followed very closely the direction of the upper flow pattern. During this period 8 low-level disturbances followed much the same track without breaking down the upper air flow pattern, which thus appeared to be uncontrolled by the low-level disturbances.

Turning to the changes which take place in the upper air pattern, Professor Rossby said that the breakdown of the "westerlies with waves" pattern generally occurred by northward surges of warm air, until the cold southward extending troughs were cut off and left as cold cyclonic vortices until finally dissipated. Conversely the anticyclonic warm northward tongues can be cut off by cold air surging to the south.

As an example of these phenomena, he showed the charts of February 12 and 20, 1948. On the 12th there was a strong westerly circulation, and on the 20th the westerlies had stopped, there was high pressure in high latitudes and a depression over France. This change was shown by coloured charts of warm and cold areas at 500 mb. to have been connected with a northward surge of warm air over the Atlantic which broke down the "westerly" circulation so that low-level disturbances were no longer steered across the Atlantic. This effect was referred to in the U.S.A. as a "blocking action". As the "blocking action" developed, a "high" contour line of the 500-mb. surface advanced steadily westwards.

Similar effects, leading to the very cold weather of January–February 1947, were illustrated with 700-mb. contour charts. The charts showed an initially strong polar cyclonic vortex followed by a divergence of contours, "blocking action", development of an anticyclone in very high latitudes, shifting of storm tracks well to the south and cold easterly winds over western Europe.

Among the points raised in the discussion (to which Sir Nelson Johnson, Mr. Gold, Professor Manley, Professor Miller, Mr. Bonacina and Mr. H. H. Lamb contributed) were means of foreseeing the development of jet streams; why, if post-glacial climatic variations were associated with the circulation index, the index should have remained much the same for thousands of years; the source of the energy of the upper air movements; and the influence of topography on the place of cutting off the cold pools. In reply Professor Rossby said there was a possibility of foreseeing the development of jet streams and advocated the placing of ocean weather ships in the best places for locating them; that the energy of the upper air movement must be provided from below, in some way not yet understood, by interaction between different air masses; and that there was a definite geographic control on the cutting off of cold pools, as there were three regions of maximum variability two of which were geographical and the third dynamically fixed from the first two.

ROYAL UNITED SERVICE INSTITUTION

Meteorology in war

The increasing importance of early consultation with the meteorologist in planning operations, particularly air operations, was stressed by the Director of the Meteorological Office in the course of a lecture given in London on February 2 to the Royal United Service Institution.

Speaking of the future, the Director said: "At the enormous speeds which are now becoming possible, the weather conditions become more critical. The meteorologist must aim at providing forecasts of increased accuracy and it is also clear that he will be required to forecast the conditions at greater heights than in the past.

"If long-range rockets are used, the heights to which meteorological information is required will be greater still.

"The meteorologist must also expect to be asked to forecast farther ahead than the 24 hours which is his present normal range. Research to this end is in progress both here and in other countries, but it would be wrong to hold out any hope of an early prospect of being able to forecast developments more than a few days ahead. Even if forecasts for three or four days ahead become possible, the predictions are likely to be in broad outline and not in detail. There is at present no prospect of being able to forecast weeks or months ahead.

"The demand by the Services for information about the conditions in the upper atmosphere coincides with what the meteorologist wants for the scientific study of his subject. It is now recognised that observations made at ground level will not take us very far, and that a full understanding of the events taking place in the atmosphere can be looked for only by a three-dimensional approach to the problem."

After referring to the effect on operations of different meteorological factors, Sir Nelson Johnson said that it was difficult to over-emphasise the importance of bringing the meteorologist into consultation right at the start of planning an operation.

He then went on to describe some of the technical aids to forecasting, pointing out that reports from the Atlantic are the most important for western European forecasting. The Germans, for instance, made floating buoys consisting of a steel tube 30 ft. long and 20 in. in diameter, surmounted by a 25 ft. high tubular aerial. These buoys sent out, automatically, by radio, every six hours, readings of

barometric pressure, and air and sea temperatures.

British methods of obtaining Atlantic weather reports included weather flights gathering information from near sea level to 18,000 ft. The positions of distant thunderstorms were plotted with the aid of radio direction finding and four such observing stations (in Bedfordshire, Cornwall, Northern Ireland and Scotland) are still functioning. The radar method of wind finding was evolved for giving wind speed and direction all the way up to 60,000 ft. within an hour. The radio-sonde was developed, consisting of a balloon and instruments which automatically signal readings of pressure, temperature and humidity in the stratosphere. By these means upper air charts, similar to ground level charts, can be drawn for 10,000 ft., 18,000 ft. and 30,000 ft.

Such charts not only permit forecasts being made of the conditions aloft, but assist in the making of accurate forecasts of the weather to be expected at the ground. These wartime advances are now standard practice.

Before closing his address with a reference to the future, Sir Nelson described the meteorological organization in war.

We await with interest the full report of the lecture and discussion to be published in the *Journal* of the Institution.

LETTER TO THE EDITOR

Pressure anomalies at Gibraltar and in the vicinity

The article by Dr. Lee, "Anomalies of barometric pressure at coastal stations"*, is of interest, especially the concluding paragraph "that anomalies of 2 mb. or more are associated with landward winds". This type of anomaly in the pressures in this region is well known, but the pressures are only anomalous in that it is impossible to derive an accurate gradient wind from them. It is not possible at the present time to undertake a large-scale investigation but the pressure difference between Gibraltar and Larache (Spanish Morocco), 80 miles south-west of Gibraltar on two occasions in October 1948 is of interest.

At 1200 on October 3 the mean-sea-level pressure at Larache (20 ft. above mean sea level) was 1015.9 mb. and at Gibraltar, North Front (8 ft. above mean sea level), was 1020.5 mb. giving a "gradient wind" of $110^{\circ} 74$ kt. between the two places. The ascent at Gibraltar at 1345 gave winds of $100^{\circ} 28$ kt. at 950 mb. veering to $160^{\circ} 7$ kt. at 750 mb., and to $180^{\circ} 17$ kt. at 550 mb.

At 0600 on October 9, the mean-sea-level pressure at Larache was 1018.0 mb. and at Gibraltar, North Front, 1019.2 mb. giving a "gradient wind" of $110^{\circ} 17$ kt. between the two. The ascent at Gibraltar at 0800 gave winds of $100^{\circ} 23$ kt. at 2,000 ft. backing to $040^{\circ} 17$ kt. at 8,000 ft. and to $360^{\circ} 20$ kt. at 16,000 ft.

There is high ground rising to 6,000 ft. east of Larache; on the 3rd Larache lay in a trough in the lee of the high ground; on the 9th as the winds aloft backed with height, Larache did not lie in a lee trough and hence the gradient wind obtained from the mean-sea-level pressure difference between Larache and Gibraltar was similar to the 2,000 ft. wind at Gibraltar.

If it is desired to smooth out these anomalous pressures a pressure which can be taken as normal must first be found. This pressure cannot be the one at Gibraltar, North Front, for as Mr. Illsley has pointed out the pressures on Gibraltar are really irregular. The observing station at Windmill Hill (392 ft. above sea level) lies two and a half miles south of that at North Front, yet with easterly surface winds the sea-level pressure at Windmill Hill is on the

**Met. Mag., London, 77, 1948, p. 201.*

average higher than at North Front. That this is not due to an error in correcting the observed reading is shown by the fact that with westerly surface winds the sea-level pressure at Windmill Hill is on the average lower than at North Front.

The table below shows the mean of the sea-level pressures at 1200 G.M.T. at both places for easterly and for westerly surface winds over the two months July and August 1947.

	North Front		Windmill Hill	
	E. winds	W. winds	E. winds	W. winds
Mean pressure (mb.)	1016·1	1015·0	1016·6	1014·9
Number of occasions	31	31	31	31

H. H. ASLETT

Gibraltar, November 10, 1948

NOTES AND NEWS

Meteorological Office aircraft electrical-resistance thermometer

In the days of slow-flying aircraft, air temperatures, wet and dry bulb, were read from a strut psychrometer of the type shown in Fig. 1, facing p. 76; the strut psychrometer consisted of large spirit-in-glass thermometers mounted in a wooden frame with a scale large enough to be seen from 10 ft. away, since the instrument was normally carried on a biplane, strapped to an inter-wing strut. With the advent of fast monoplanes, the strut psychrometer became obsolete because of its awkward shape and size and large air resistance. To replace it a new type of thermometer was designed which would have a small air resistance, be distant-reading, be easily fitted to aircraft with pressurised cabins (the mercury-in-steel thermometer is at a disadvantage here) and be accurate to within half a degree centigrade. The Meteorological Office aircraft electrical-resistance thermometer, which was designed by A. W. Brewer while with the Meteorological Research Flight during the war, satisfies all these requirements. This thermometer is shown between pp. 76 and 77 in Fig. 2 as both dry and wet bulb, and mounted on an aircraft in Fig. 3. The thermometer element which appears on the right of Fig. 2 and in Fig. 4 has a platinum resistance wire wound on a mica former which is made up of three thin mica sheets pressed together, two thin copper strips which serve as terminals being sandwiched in between. The former with the platinum resistance wire is then covered on both sides with two more mica sheets and inserted into a flat brass sheath which is mounted on a bakelite terminal block on a base plate so that the flat surface is parallel to the direction of flight when in position. A radiation shield, which also acts as a support for the thermometer at its extremity, protects the element on both sides. The element can also be adapted for use as a wet bulb by mounting it in a wet-bulb housing as shown on the left of Fig. 2 and in Fig. 5.

The principle of the resistance thermometer depends on the change of resistance in the platinum element with changes in temperature, the relation being almost linear. Together with the ballast resistance, contained in the terminal block, the platinum element in this thermometer has a fundamental interval of 40 ohms.

The resistance is measured by a Wheatstone bridge, having compensating leads in the three-wire system, which is contained in a box $4\frac{1}{2}$ in. $\times$ 5 in. $\times$ $2\frac{1}{2}$ in. suitable for mounting in the cockpit of single-engined aircraft. This part is shown in the centre of Fig. 2. The galvanometer, whose indicating needle can be seen in the inset on the face of the instrument, is connected to a sliding contact which is moved over a nichrome resistance wire, stretched round the circumference of an insulating disc, until a balance is found. The contact is moved by rotating the large knob, which can be seen on the front of the instrument, and which is geared in the ratio 9 : 1.

The scale, which covers a range from -110°F. to $+100^{\circ}\text{F.}$, is engraved on a circular dial of 4-in. diameter which rotates with the sliding contact against a single fiduciary mark engraved on the instrument face. At the lower temperatures 1°F. corresponds to about 1.1 mm. of scale while at the higher temperatures the correspondence is 1°F. to approximately 2 mm. of scale. The accuracy demanded of the instrument is $\pm 1^{\circ}\text{F.}$ ($\frac{1}{2}^{\circ}\text{C.}$) which requires that the scale be read to $\pm \frac{1}{2}^{\circ}\text{F.}$ ($\frac{1}{4}^{\circ}\text{C.}$) which is possible with this scale over the whole range.

The instrument is robust and can withstand vibration but extremes of cockpit temperature can affect the accuracy of the bridge; such extremes, however, are rare in modern aircraft.

Before the true air temperature can be determined a speed correction has to be applied to the readings.* This correction arises through the generation of heat in the boundary layers due to the motion of the thermometer through the air which is communicated as a rise in temperature to the thermometer. The heat thus generated consists of two parts—the part due to adiabatic rise in pressure and the part due to dissipation in the surface layers.

A balance is struck between the heat gained in this manner and the heat lost by conduction through the boundary layer. If the thermometer is shaped like a knife blade cutting into the wind the pressure term can be neglected and the equation of motion of the air can be solved by a method first indicated by Pohlhausen† giving the temperature of the “flat-plate” as

$$T = T_0 + \Delta(\sigma)$$

$$\text{where } \Delta(\sigma) = \frac{u_0^2}{2\bar{f}c_p} \sigma^{\frac{1}{2}} \text{ very nearly}$$

u_0 = speed of airflow (true speed of the aircraft)

$\bar{f}$ = mechanical equivalent of heat

c_p = specific heat of air at constant pressure

σ = Prandtl's number

This formula has been verified experimentally by Hilton.‡

Besides the advantage of an easily calculable speed correction, the “flat plate” offers small resistance to the airflow and is not adversely affected by icing or by rain as is, for example, the thermometer in which the temperature rise is due solely to the adiabatic pressure increase, e.g. the thermometer mounted inside a pitot tube.

*see “Meteorological Air Observers Handbook”, 1945, p. 14.

†POHLHAUSEN; *Z. angew. Math. Mech.*, Berlin, 1, 1921, p. 115.

‡HILTON, W. F.; Thermal effects on bodies in an air stream. *Proc. roy. Soc., London, A*, 168, 1938, p. 43.

This thermometer has now undergone prolonged flight tests and has proved to be highly satisfactory. It compares favourably with the older type of strut psychrometer, except in one point—the lag—which is about the same for both but which is open to improvement by modifying slightly the design. Flight tests show the speed correction to be $1.7 (V/100)^2$ in degrees Fahrenheit where V is the true air speed in knots.

A later modification made in stainless steel for increased rigidity is about to appear. It will be used in the wet-bulb housing where its increased strength is required.

D. D. CLARK

REVIEWS

Einführung in die Bioklimatologie, by Hellmut Berg, 8vo, 8 in. $\times$ 5 $\frac{3}{4}$ in., pp. iv. + 131, *Illus.*, H. Bouvier u. Co., Verlag Bonn. Price: DM. 7.50.

Hitherto the literature of bioclimatology has consisted of a very large number of original papers and a few encyclopædic works on special portions of the subject. Professor H. Berg of the University of Cologne in his new introduction to bioclimatology for meteorologists, has set out to meet a very real need for an elementary work on the whole subject.

Professor Berg takes a very broad view of bioclimatology, which he defines as concerned with the direct and indirect effects and interactions of the meteorological elements on life. Thus he naturally discusses the special climate of crop fields and forests as well as the effects of meteorological factors on plant life. Not quite so obviously, perhaps, he includes the climate of cities in bio-climatology as well as the effects of weather on man.

The book is divided into seven main sections:—

- A. Radiation as a bioclimatological element
- B. Climate of the layers of air next the ground, between the plants and in forests
- C. Agricultural meteorology and phenology
- D. Town climate
- E. Climate of dwelling rooms, factories, and greenhouses
- F. Measures of the composite effect of meteorological elements on life
- G. Weather and disease.

Section A provides an admirable description of radiation as affecting life with special attention to ultra-violet radiation. The outgoing radiation from plants and animals is not, however, neglected.

Section B distinguishes between the “large climate” of the well exposed stations of the synoptic reporting network, the “small climate” of a particular part of the landscape such as a valley or the different slopes of a hill, and, finally, the “microclimate” of the air layer next to the ground or within the plants or forest. “Small” and “micro” climates are very thoroughly treated from frost hollows to the air currents set up by the difference of temperature between a wood and surrounding open country. Three pages are devoted in this section to the effect of forests on rainfall in which, on the basis of a comparison of 8 years’ readings in a growing forest in Germany with surrounding open country readings, he concludes that a forested area has up to 20 per cent. more rainfall than surrounding open country.

Only a relatively small section is devoted to agricultural meteorology and phenology. It is mainly concerned with the correlation between temperature and rainfall in spring with the subsequent harvest and the variation of this correlation with place. Protection of plants from frost is dealt with in detail. Of course much that is sometimes classed as agricultural meteorology has found a place in the previous section of the book.

Most aspects of the climate of cities are described in the next sections, special attention being given to temperature, visibility and rainfall. Examples are drawn mainly from Cologne but also from New York, London, Munich and Bremen.

The short section on the climate of rooms, factories, and greenhouses brings together much useful information including details of methods of air conditioning not readily available elsewhere.

With the section on measures of the composite effect of meteorological conditions we come to the effects of weather on man. The "measures" are Linke's Luftkorper, which are not quite the same as the air masses of synoptic meteorology, and the "rate of cooling" of a body at the temperature of the human skin determined by Hill's katothermometer and Dorno's frigorigimeter. Tables of the rate of cooling are given for the main climatic regions and for the various types of air mass affecting central Europe.

The last section gives a very careful study of the elusive subject of the effects of weather on disease. In Germany and Austria much effort has been spent in attempts to ascertain pathological effects of the passage of fronts, the föhn, etc., by analysing statistics of the onset of certain illness on the days before, on, and after the occurrence of the particular meteorological phenomenon. There seems to be some evidence for real effects in the case of some diseases, notably apoplexy. Distinction is drawn between "meteorotropic" diseases for which meteorological events seem to provide a trigger action and seasonal illnesses whose incidence is not directly related to weather but more to seasonal changes in living conditions. The pitfalls which await the unwary in this subject on both the meteorological and medical sides are carefully noted.

The book concludes with a short bibliography in which only German books are given. Dr. Berg has given a great deal in the space at his disposal. Nevertheless, there are some items the reviewer considers might have found a place, if necessary at the expense of some relatively minor matters such as the "country breeze" between open country and a city which is described at length. Outstanding among the items referred to are :—

- (a) shelterbelts in agricultural meteorology,
- (b) transpiration of water vapour by trees and its effect on forest climate and the state of the soil,
- (c) the subject best described by the title of Markham's book "Climate and the energy of nations".

The author has no doubt suffered from lack of information from outside Germany during and since the war. Thus, his account of atmospheric pollution would have gained from a study of the Leicester pollution report.*

*London, Department of Industrial and Scientific Research, Atmospheric Pollution Research Committee. Atmospheric pollution in Leicester—A scientific survey. *Tech. Pap. D.S.I.R., London*, No. 1, 1945.

As it is he does not refer to the importance of the lapse-rate of temperature in the dispersal of industrial smoke. Similar comment applies to the recent work of Brunt on the human heat balance and tolerable climatic conditions.

The price of 7.50 *DM* is, at the rate of exchange of 1s. 6d. to the mark, somewhat expensive for a paper-covered book of this size.

In spite of these criticisms there is no other book quite like this one which is strongly to be recommended.

G. A. BULL

On radiational cooling of the earth's surface during the night, especially with regard to the prediction of ground frosts, by P. Groen. *Meded. ned. met. Inst., de Bilt*, Serie B, 1, Nr. 9. Size : $12\frac{1}{4}$ in. $\times$ $8\frac{3}{4}$ in., pp. 35. Rijksuitgeverij, The Hague, 1947. Price : *Fl.* 2,50.

In the present paper Dr. Groen first discusses the theoretical formulæ derived by Brunt* and Philipps† for predicting the nocturnal radiational cooling of the ground, and then endeavours to eliminate certain of their simplifying assumptions which are at variance with observations. His assumption of a linear variation of effective radiation with decrease of temperature appears to be an improvement on the earlier assumptions of a constant effective radiation but his assumption of an initial linear distribution of temperature with depth in the ground is more debatable.

In Brunt's discussion of the problem the flow of heat from the air to the ground and the heat released by the deposition of dew are ignored, which leads to an overestimate of the degree of cooling. Philipps took into account the first of these by assuming that the air had a constant coefficient of eddy conductivity, but Dr. Groen objects to this on the grounds that it is unlikely that the coefficient of eddy conductivity is a constant and that the role of radiation in the heat exchange of the air has been neglected. In view of the difficulties in dealing with these aspects of the problem, Dr. Groen abandons theory in favour of empiricism. It is difficult to see the value of the present approach and the theoretical approach of J. C. Jaeger‡ would appear to be not only simpler but far superior.

R. FROST

Interdiurnal variations of pressure and temperature in the upper atmosphere over North India, by M. W. Chiplonkar. Scientific Notes of the India Meteorological Department. Vol. IX, No. 109. 8vo. pp. 81-92. Delhi, Manager of Publications, 1947. Price : *Annas* 14 or 1s. 3d.

M. W. Chiplonkar has analysed the changes of pressure and temperature at various levels over Agra on 114 pairs of days in winter. The data were taken from published results of sounding-balloon ascents, and the time interval between the ascents was usually 24 hours. The analysis follows the lines adopted by Haurwitz and other American authors in treating European and North American data.

*BRUNT, D.; Notes on radiation in the atmosphere. *Quart. J. R. met. Soc., London*, 58, 1932 p. 389.

†PHILLIPPS, H.; Zur Theorie der Wärmestrahlung in Bodennähe. *Beitr. Geophys., Stuttgart*, 56, 1940, p. 229.

‡JAEGER, J. C.; Note on the effect of wind on nocturnal cooling. *Quart. J. R. met. Soc., London*, 71, 1945, p. 388.

The pairs of observations are classified according to the sign of the pressure change at the ground, and the corresponding mean pressure and temperature changes at upper levels are tabulated and graphed. The results obtained in this way are not always easy to interpret, but Chip lonkar finds that the pressure and temperature variations over North India, although smaller than those over Europe and North America, have a broadly similar distribution with height.

It is unfortunate that no indication is given of instrumental accuracy, since errors so introduced would increase upward and if large enough would distort the apparent height variation of the interdiurnal changes. However, Chip lonkar finds that pressure changes at 6-11 Km. are as great or greater than those at the surface, and that pressure changes at 4 Km. are more definitely associated with tropospheric temperature changes. Perhaps we may conclude that upper air isobaric charts might provide a useful tool in north India where surface isobars are very difficult to interpret.

J. S. SAWYER

NEWS IN BRIEF

Mr. R. H. Mathews, B.A., has been appointed Assistant Director (Climatology) of the Meteorological Office.

OBITUARY

Father F. J. Rowland, S.J.—The news of the death of Father F. J. Rowland, S.J., Director of the Stonyhurst College Observatory from 1932 to 1947 has been received. Before becoming Director Father Rowland worked in the Observatory for many years under Father O'Connor his predecessor.

A note on the meteorological work of the Stonyhurst Observatory was published in the August 1948 number of this magazine.

The Observatory, under Father Rowland's control, was very actively engaged in terrestrial magnetism, solar physics, and in seismology as well as in meteorology.

WEATHER OF JANUARY 1949

On the first day of the month a very deep depression moved north-north-east across Ireland and Scotland, and other depressions moved eastwards across the British Isles on the 4th, and across northern Scotland during the night of the 7th. Subsequently the tracks of depressions were mostly far to the north and north-west of Scotland, and anticyclones lay near to or over the British Isles, mostly to southward and south-westward of these islands up to the 22nd, and then over the continent. An anticyclone, centred directly over the British Isles on the 30th and 31st, gave readings above 1044 mb. over Ireland and most of England during the morning of the 30th.

Mean pressure for the month was above 1025 mb. between the Azores and southern Germany. It was above 1020 mb. over most of North America, and above 1025 mb. over an area including the most westerly States of the U.S.A. and the south-west of Canada, but was below 990 mb. between Jan Mayen and the north of Norway. Mean pressure was above normal by more than 10 mb. around British Columbia and by more than 5 mb. in an area between Nova Scotia and Hungary bounded roughly by latitudes 45° and 55°N. The only region with pressure much below the normal included Finland, Scandinavia and the Arctic Ocean, the deficit exceeding 10 mb. in northern Scandinavia.

In the British Isles the weather was unsettled and wet in the north-west and extreme north and dry and sunny on the whole in the south and east. Westerly winds and mild conditions predominated. Pressure fell to the

exceedingly low level of 950 mb. at Holyhead on the 1st and the monthly range of pressure at Kew Observatory, namely 82 mb., was the greatest in any one month since observations began there in 1869.

On the 1st an intense depression centred over Ireland moved north-east and then turned north to a position off west Norway by the morning of the 3rd. South-westerly gales occurred in south England, and north-easterly gales in north Scotland on the 1st, while gusts of 78 kt. and 71 kt. were registered respectively at Tangmere, Sussex, and Manston, Kent. Heavy rain fell locally in Scotland; for example 2.33 in. at Achfary, Sutherland. In the rear of this disturbance cold winds of polar origin prevailed in the British Isles. On the 4th a depression moved from north-west Ireland to East Anglia and snow fell in Northern Ireland, north England and extreme south-west Scotland, while over parts of Scotland frost continued throughout the day. By the 6th pressure was high from the Bay of Biscay across France to the Caspian Sea; meanwhile a weak trough of low pressure moved across north Ireland and south Scotland giving considerable rain locally in Scotland and the Lake District with 2.00 in. at Borrowdale, Cumberland. On the 7th a depression moved east over Scotland and caused widespread gales on the 7th and 8th and further rain, particularly in the west and north. Meanwhile an intense anticyclone developed on the Atlantic and subsequently drifted south where it remained off our south-west coasts until the 21st. During this period deep depressions to the north of Scotland moved east giving gales locally, chiefly in the northern half of the country, on the 11th, 16th, 17th, 19th and 20th and mainly mild weather, dry on the whole over most of England but wet in the north and west of Scotland. On the 18th, 2.18 in. of rain was measured at Inveraray Castle Gardens, Argyll, and 2.03 in. at Fort William. Subsequently the anticyclone moved slowly east and on the 24th and 25th a new high moved east across England to central Europe; mainly dry conditions became established over most of the British Isles, apart from rain at some places in the west and north. There was a good deal of fog at some inland stations in England from the 26th to 29th; it was particularly thick in parts of London on the 29th. The week ending the 29th was, however, very sunny at those places which escaped most of the fog. On the 29th yet another anticyclone developed off the west of Ireland and moved east. On the 31st a small disturbance off the north of Scotland moved south-east over the North Sea and was associated with slight rain over much of the country.

The month was wet in the west and north of Scotland, more than twice the average rainfall occurring over much of Sutherland, but less than the average in the east and extreme south-west of Scotland. In England and Wales it was the driest January over the country since 1911.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	57	17	+2.1	58	—4	114	22
Scotland	57	0	+1.4	127	+1	87	16
Northern Ireland..	54	15	+2.6	104	0	86	16

RAINFALL OF JANUARY 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	·75	40	<i>Glam.</i>	Cardiff, Penylan ..	1·24	34
<i>Kent</i>	Folkestone, Cherry Gdns.	1·69	75	<i>Pemb.</i>	St. Ann's Head ..	·96	28
<i>"</i>	Edenbridge, Falconhurst	1·37	56	<i>Card.</i>	Aberystwyth ..	2·23	69
<i>Sussex</i>	Compton, Compton Ho.	1·44	45	<i>Radnor</i>	Bir. W. W., Tyrmynydd	3·37	53
<i>"</i>	Worthing, Beach Ho. Pk.	1·25	54	<i>Mont.</i>	Lake Vyrnwy ..	4·71	85
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	1·08	42	<i>Mer.</i>	Blaenau Festiniog ..	11·20	110
<i>"</i>	Bournemouth ..	·76	28	<i>Carn.</i>	Llandudno ..	2·36	98
<i>"</i>	Sherborne St. John ..	1·11	48	<i>Angl.</i>	Llanerchymedd ..	3·10	98
<i>Herts.</i>	Royston, Therfield Rec.	1·21	70	<i>I. Man.</i>	Douglas, Boro' Cem. ..	2·91	87
<i>Bucks.</i>	Slough, Upton ..	1·09	59	<i>Wigtown</i>	Port William, Monreith	2·25	69
<i>Oxford</i>	Oxford, Radcliffe ..	·91	50	<i>Dumf.</i>	Dumfries, Crichton R.I.	2·43	76
<i>N'hant.</i>	Wellingboro', Swanspool	·73	39	<i>"</i>	Eskdalemuir Obsy. ..	6·81	126
<i>Essex</i>	Shoeburyness ..	·86	64	<i>Roxb.</i>	Kelso, Floors ..	2·21	126
<i>Suffolk</i>	Campsea Ashe, High Ho.	·95	52	<i>Peebles</i>	Stobo Castle ..	4·18	139
<i>"</i>	Lowestoft Sec. School ..	1·12	67	<i>Berwick</i>	Marchmont House ..	1·83	81
<i>"</i>	Bury St. Ed., Westley H.	1·09	61	<i>E. Loth.</i>	North Berwick Res. ..	1·54	90
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·20	62	<i>Mid'n.</i>	Edinburgh, Blackf'd. H.	2·16	123
<i>Wilts.</i>	Bishops Cannings ..	1·10	47	<i>Lanark</i>	Hamilton W. W., T'nhill	4·37	133
<i>Dorset</i>	Creech Grange ..	1·15	35	<i>Ayr</i>	Colmonell, Knockdolian	3·94	91
<i>"</i>	Beaminster, East St. ..	1·06	30	<i>"</i>	Glen Afton, Ayr San ..	..	..
<i>Devon</i>	Teignmouth, Den Gdns.	·45	15	<i>Bute</i>	Rothsay, Ardencraig	5·99	133
<i>"</i>	Cullompton ..	·97	30	<i>Argyll</i>	L. Sunart, Glenborrodale	9·15	129
<i>"</i>	Barnstaple, N. Dev. Ath.	1·18	36	<i>"</i>	Poltalloch ..	7·21	142
<i>"</i>	Okehampton, Uplands	2·40	47	<i>"</i>	Inveraray Castle ..	13·92	169
<i>Cornwall</i>	Bude School House ..	1·27	42	<i>"</i>	Islay, Eallabus ..	5·46	117
<i>"</i>	Penzance, Morrab Gdns.	1·97	52	<i>"</i>	Tiree ..	4·99	117
<i>"</i>	St. Austell, Trevarna ..	2·14	50	<i>Kinross</i>	Loch Leven Sluice ..	3·61	115
<i>"</i>	Scilly, Tresco Abbey ..	1·46	46	<i>Fife</i>	Leuchars Airfield ..	1·04	57
<i>Glos.</i>	Cirencester ..	1·19	47	<i>Perth</i>	Loch Dhu ..	10·39	114
<i>Salop.</i>	Church Stretton ..	1·72	66	<i>"</i>	Crieff, Strathearn Hyd.	..	..
<i>"</i>	Cheswardine Hall ..	2·10	95	<i>"</i>	Pitlochry, Fincastle ..	2·75	79
<i>Staffs.</i>	Leek, Wall Grange P.S.	1·69	58	<i>Angus</i>	Montrose, Sunnyside ..	1·28	64
<i>Worcs.</i>	Malvern, Free Library	1·20	54	<i>Aberd.</i>	Balmoral Castle Gdns. ..	2·07	75
<i>Warwick</i>	Birmingham, Edgbaston	1·38	68	<i>"</i>	Dyce, Craibstone ..	1·85	78
<i>Leics.</i>	Thornton Reservoir ..	1·18	60	<i>"</i>	Fyvie Castle ..	2·44	103
<i>Lincs.</i>	Boston, Skirbeck ..	1·06	65	<i>Moray</i>	Gordon Castle ..	2·61	129
<i>"</i>	Skegness, Marine Gdns.	1·15	66	<i>Nairn</i>	Nairn, Achareidh ..	2·87	159
<i>Notts.</i>	Mansfield, Carr Bank ..	1·01	47	<i>Inv's</i>	Loch Ness, Foyers ..	7·66	182
<i>Ches.</i>	Bidston Observatory ..	2·14	101	<i>"</i>	Glenquoich ..	22·29	162
<i>Lanes.</i>	Manchester, Whit. Park	2·07	82	<i>"</i>	Fort William, Teviot ..	14·22	147
<i>"</i>	Stonyhurst College ..	3·19	75	<i>"</i>	Skye, Duntuiln ..	6·66	126
<i>"</i>	Blackpool ..	2·12	78	<i>R. & C.</i>	Ullapool ..	5·65	127
<i>Yorks.</i>	Wakefield, Clarence Pk.	·82	43	<i>"</i>	Applecross Gardens ..	8·89	163
<i>"</i>	Hull, Pearson Park ..	·89	49	<i>"</i>	Achnashellach ..	16·47	181
<i>"</i>	Felixkirk, Mt. St. John	·82	41	<i>"</i>	Stornoway Airfield ..	6·05	123
<i>"</i>	York Museum ..	·68	38	<i>Suth.</i>	Lairg ..	7·84	239
<i>"</i>	Scarborough ..	·87	43	<i>"</i>	Loch More, Achfary ..	15·92	219
<i>"</i>	Middlesbrough ..	·60	37	<i>Caith.</i>	Wick Airfield ..	3·99	162
<i>"</i>	Baldersdale, Hury Res.	2·11	65	<i>Shet.</i>	Lerwick Observatory ..	5·68	133
<i>Nor'ld.</i>	Newcastle, Leazes Pk. ..	·58	29	<i>Ferm.</i>	Crom Castle ..	3·41	102
<i>"</i>	Bellingham, High Green	2·31	81	<i>Armagh</i>	Armagh Observatory ..	2·41	96
<i>"</i>	Lilburn Tower Gdns. ..	1·05	51	<i>Down</i>	Seaforde ..	2·18	69
<i>Cumb.</i>	Geltsdale ..	2·80	100	<i>Antrim</i>	Aldergrove Airfield ..	2·48	91
<i>"</i>	Keswick, High Hill ..	4·42	88	<i>"</i>	Ballymena, Harryville ..	3·53	95
<i>"</i>	Ravenglass, The Grove	3·06	91	<i>Lon.</i>	Garvagh, Moneydig ..	3·59	104
<i>Mon.</i>	Abergavenny Larchfield	1·33	39	<i>"</i>	Londonderry, Creggan	5·74	159
<i>Glam.</i>	Ystalyfera, Wern House	3·54	56	<i>Tyrone</i>	Omagh, Edenfel ..	4·16	118

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, SEPTEMBER 1948

STATIONS	PRESSURE		TEMPERATURES						RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE				
	Mean of day M.S.L.	Diff. from normal	Absolute		Mean values						Total	Diff. from normal	Days	Daily mean	Per-centage of possible		
			Max.	Min.	°F.	°F.	°F.	°F.								°F.	°F.
London Kew Observatory	mb.	mb.	F.	°F.	°F.	°F.	°F.	°F.	°F.	tenths	in.	in.	hr.	%			
1017.2	0.0	74	39	65.1	51.6	58.3	+0.8	55.0	7.2	1.24	-0.63	9	5.1	41			
1017.8	+0.6	84	61	79.0	66.3	72.7	+0.3	68.1	3.1	0.00	—	0	10.4	84			
1016.4	+0.1	84	63	80.0	67.4	73.7	-2.3	70.2	5.1	0.05	—	3	9.6	77			
1018.2	-0.5	67	52	62.5	54.5	58.5	+1.6	54.5	9.9	1.03	-1.22	8	—	—			
1012.9	—	86	69	82.9	72.9	77.9	—	74.3	8.8	22.59	—	27	—	—			
1013.5	+1.3	87	68	83.7	69.8	76.7	-2.0	74.1	9.3	2.62	—	14	3.1	26			
1011.6	—	89	62	84.5	66.5	75.5	-0.4	60.5	2.0	10.22	-1.28	23	5.6	46			
1018.4	-0.2	93	51	82.7	60.5	71.6	-0.9	60.5	1.6	0.04	-0.14	1	8.3	69			
1014.5	0.0	94	44	85.7	56.8	71.3	-0.2	54.8	1.4	0.00	-0.04	0	9.8	82			
1016.3	-1.4	88	38	78.8	53.1	65.5	-0.3	52.3	4.4	0.00	-0.20	0	9.5	79			
Cape Town	1019.0	-0.1	87	64.8	48.5	56.7	-1.2	48.3	6.6	2.68	+0.44	15	—	—			
Germiston, South Africa	1019.0	+0.6	80	74.8	46.7	60.7	+1.0	45.0	1.0	0.04	-0.77	2	10.6	89			
Mauritius	1000.2	-4.3	94	77	89.5	84.3	+1.1	79.8	7.7	6.50	-3.51	19	4.6	37			
Calcutta, Alipore Obs.	1006.8	-1.2	89	73	85.4	80.7	-0.2	75.9	7.5	11.78	+1.10	23	4.6	37			
Bombay	1005.8	-0.7	101	73	94.1	85.9	+0.7	75.2	8.2	4.14	-0.71	14	5.5	45			
Madras	1010.1	+0.2	88	72	86.3	81.4	+0.2	76.1	6.9	2.18	-2.58	14	8.2	67			
Colombo, Ceylon	1009.9	+0.1	91	73	87.6	81.7	+0.6	76.7	7.8	5.62	-1.17	13	—	—			
Singapore	1008.1	-0.2	92	71	86.6	81.5	+0.5	76.9	—	22.85	+13.16	16	6.4	52			
Hong Kong	1016.1	0.0	84	44	68.0	59.6	+0.4	53.3	6.3	2.83	-0.03	12	6.5	55			
Sydney, N.S.W.	1014.9	-0.9	79	37	65.8	55.7	+1.6	50.0	5.5	1.96	-0.48	15	5.7	48			
Melbourne	1017.6	+0.1	88	43	67.9	58.3	-0.1	51.2	6.9	0.69	-1.39	10	6.2	53			
Adelaide	1017.3	-0.2	77	43	66.6	58.1	-0.1	54.5	5.2	5.07	+1.65	13	6.2	52			
Perth, W. Australia	1017.5	+0.3	89	38	74.5	60.9	+2.2	50.3	2.8	0.48	-0.19	3	—	—			
Coalgardie	1015.9	-1.7	90	47	74.6	64.7	-0.5	57.1	3.7	2.98	+0.98	7	8.2	69			
Brisbane	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
Hobart, Tasmania	1013.4	-1.2	64	40	57.8	51.9	+1.8	49.3	7.8	1.37	-2.60	14	5.3	45			
Wellington, N.Z.	1013.0	-1.3	88	64	81.2	75.5	+1.0	71.2	6.6	1.72	-5.97	12	6.5	54			
Suva, Fiji	1011.8	0.0	87	68	85.5	78.7	-0.2	75.8	3.2	2.34	-3.20	10	9.3	78			
Apia, Samoa	1011.5	-0.7	95	72	90.5	82.7	+1.2	76.7	4.8	5.34	+1.31	10	7.5	61			
Kingston, Jamaica	—	—	90	72	87.0	81.2	+0.9	77.8	7.7	4.51	-3.48	19	—	—			
Grenada, W. Indies	1018.0	+0.2	90	44	75.5	65.8	+5.5	55.4	5.7	2.22	-0.45	7	7.5	60			
Toronto	1015.4	+1.6	93	37	75.2	49.1	+8.4	46.2	5.0	0.05	-2.71	3	8.3	66			
Winnipeg	1015.7	-1.7	76	40	64.7	56.8	+0.9	51.3	6.4	1.75	-1.99	11	5.9	47			
St. John N.B.	1016.2	-0.2	77	38	63.8	55.7	-0.4	48.8	5.2	1.81	0.00	9	7.1	56			
Victoria, B.C.	—	—	—	—	—	—	—	—	—	—	—	—	—	—			

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ORGANIZATION OF RESEARCH IN THE METEOROLOGICAL OFFICE

By A. H. R. GOLDIE, D.Sc., F.R.S.E.

Early years.—The Meteorological Office has always had an interest in research; the selection or establishment of seven observatories in 1867 by the Meteorological Committee of the Royal Society was one of the early steps towards providing data for exact investigation of weather phenomena. But it was only from about 1906 that the governing body took definite action to offer a career in research to its own staff.

In the *Report of the Meteorological Committee* for the year ending March 31, 1906, we read that two new appointments apart from the Directorship (then held by Mr. W. N., afterwards Sir Napier, Shaw) were created in the Meteorological Office, to be filled by men of "high scientific attainments", namely the posts of Superintendent of Statistics and Superintendent of Instruments. Mr. R. G. K. Lempfert and Mr. E. Gold were appointed to these posts. In the same report we read also that the Commission had been fortunate in securing the services of Mr. W. H. Dines, F.R.S., for the organization and control of experiments for the investigation of the upper air^{1*}. And later we read that Mr. G. C. Simpson (afterwards Sir George Simpson, Director of the Office 1920–1938) who was acting as volunteer assistant to the Director had made arrangements for kite ascents in Derbyshire. In these appointments we see the beginnings of meteorology as a recognised profession offering a career for men "of high scientific attainments".

In the years that followed, up to the outbreak of the first world war in 1914, a number of well-known names became identified with meteorology—L. F. Richardson, G. I. Taylor, G. M. B. Dobson, F. J. W. Whipple, R. Corless, the Dines brothers, whilst Chree was active in geophysics at Kew. Outside the Office Rayleigh, Schuster, Aitken, Lyons, Chapman and others were active. Within this period the Meteorological Office and its associated workers made a tremendous contribution to the science of meteorology. The office organization developed, but a substantial part of the time of each scientific officer continued to be expended on scientific research and investigation.

*These numbers refer to the list of references on p. 97.

Period 1914-39.—The outbreak of war in 1914 brought new requirements into which a great part of the scientific and technical staff was rapidly absorbed. At the end of the war a greatly increased office was transferred to the Air Ministry, and the services required by aviation imposed henceforth a major demand on the resources available. Research did not die out but it occupied only a slender place in official organization, and the bulk of the research work actually published in the next 20 years came from individuals who had to encroach more or less heavily on their private time to accomplish it. Officially sponsored research included, however, such major items as the expedition to Fort Rae (our main contribution to the International Polar Year 1932-33), part of the effort of the observatories and such investigations as those carried out on wind structure at Cardington in connexion with airship design or at Porton on turbulence.

Period since 1939.—In 1939 plans were in hand to set up a research organization and a Meteorological Research Committee. The outbreak of the second world war interrupted these plans, but in 1941 the Committee came into existence. Its members are appointed by the Secretary of State for Air^{2,3}.

Within the last year three sub-committees have been set up to deal respectively with instruments, synoptic and dynamical problems, and physical problems. At the same time, within the Meteorological Office, the co-ordination of research and the task of liaison with other bodies have been centralised in a Deputy Directorate of Research, with three Divisions concerned respectively with general research, special investigations and instruments. Comprised in the first of these divisions are the observatories at Kew, Eskdalemuir and Lerwick, the Branch Office at Edinburgh, the Meteorological Research Flight⁴, special stations at Cambridge, Rye and East Hill, and a branch at Headquarters concerned with administration and secretarial duties. Research in weather forecasting is provided for separately by a Division under the control of the Deputy Director for Forecasting, whilst research in climatology and marine meteorology is covered by the Divisions concerned with these subjects and controlled by the Deputy Director (Services).

From this it will be seen that research in some degree now pervades all parts of the Office, and indeed the broad intention is that some element of research or original inquiry should enter into the duties of all staff of the scientific officer category; work which has developed to the stage of routine—even a professional and highly specialised routine—should so far as possible be passed to the experimental officer and assistant grades.

Results of recent years.—The difficulties of publishing during and since the war have made it not easy for those outside official circles to appreciate the extent of the advances made in meteorology in the past 10 years. Here it is only possible to present a brief summary of the position.

Upper air.—Investigation of the upper air had been going on for many years before 1939, but from 1939 the tools for the job developed greatly and the general tempo increased rapidly. Within a few years measurements were being obtained four times a day, at several stations in the British Isles, of temperature and pressure by radio methods⁵, and of wind by the use of radar⁶, to a height of over 50,000 ft. The present aim is to increase the height to 100,000 ft. By radio methods humidity can as yet be measured with reasonable accuracy only up to about 25,000 ft. The Dobson-Brewer frost-point

hygrometer, however, developed about 1942-43, enables humidity to be measured accurately to the lowest temperature reached in the atmosphere. The instrument requires an observer to operate it, but it is now in regular use on the high-flying aircraft of the Meteorological Research Flight, and has produced new knowledge about the upper troposphere and lower stratosphere. The air in the stratosphere is found to be intensely dry, at all events when the tropopause is low, the relative humidity then being frequently of the order of only 1 per cent. This peculiarity probably throws light on the circulation of the air in the stratosphere over the globe; there is only one region, namely in the upper troposphere and lower stratosphere within the tropics, where air at high levels is cooled to frost points of the order now being observed in the stratosphere in England. The first inference, therefore, is that the air of the lower stratosphere in temperate latitudes is air which at some time previously has passed through the upper troposphere in the tropics and has not since returned to lower levels.

The accumulated observations of wind have been analysed statistically to obtain the frequencies of winds of different speeds and directions in the different seasons of the year, also the variability of wind with distance and time. Obviously such information is of fundamental importance in estimating the potentialities of aircraft, the possibilities of navigation by dead reckoning, problems of long-range artillery, etc. Methods of using the upper air data in forecasting the weather, and more particularly the upper winds, have been investigated.

Exact measurements of the type described above, exist as yet only for certain regions. Outside western Europe, North America and a few places in India, the observational material is scanty. A few years ago attention was therefore turned to theoretical methods of computing and charting approximately the wind distribution over the globe as a whole for the different seasons of the year. A comparison of the theoretically computed "wind roses" with the actual observations in the regions where observations are available suggests that a useful degree of reliability attaches to these charts, but it is considered of great importance that further observational material be obtained, particularly in the tropics and in high latitudes.

Using the data just mentioned and a special technique, expectations of the frequency with which aircraft would encounter headwinds of various strengths on any desired route up to 40,000 ft. can be derived. Sometimes it has been possible to check the computations against the frequencies experienced by aircraft on regular routes and the checks have proved satisfactory.

For a period of a year, a series of measurements of wind at 100,000 ft. was made in the south of England, using as a pointer the burst of a shell which could be sent to that height by a hyper-velocity gun belonging to the Royal Marine Siege Regiment. The results showed that at these great heights the wind is easterly from about May to August, with speed up to about 30 m.p.h.: during the rest of the year it is westerly, the speed at mid-winter rising to about 100 m.p.h.

By indirect and less positive methods based on observations of the travel of sounds from explosions, the winds and temperatures have been estimated up to about 150,000 ft. These results point for the first time to a substantial variation of temperature throughout the year at this level.

Using the results just described and further theoretical estimates, an approximate cross-section of average winds and air densities for summer, winter, spring and autumn from north pole to equator and up to a height of 150,000 ft. has been computed. Here again, the observational material for very high levels being confined to the British Isles, the obvious next requirement is material for tropical regions and high latitudes.

Wind structure.—Turbulence or the structure of eddies or gustiness of wind enters into questions of the design and strength of aircraft, and into many military problems. With increasing speed of aircraft, the importance of wind structure and information as to how it varies at different heights becomes ever greater. A gust which would not seriously affect an aircraft travelling at 150 m.p.h. could have alarming results at 500 m.p.h. Considerable information has been acquired in the past 35 years about wind structure, diffusion, etc., in the lower layers of the air, but the problem as affecting the higher levels is one of great complexity. Measurements made from aircraft, or indeed from any moving body, have inevitably a bias depending on the dimensions, speed, aerodynamic properties, etc., of the machine itself. The worst conditions are probably experienced in cumulonimbus clouds where visual observation is ruled out.

Cloud physics.—In the early part of the war, the making of a condensation trail constituted a grave risk to aircraft, however high, when flying over enemy territory. A theoretical investigation yielded the useful result that above a certain temperature, which could be computed for each height, there should be immunity from exhaust trails. The meteorological research section of the High Altitude Flight at Boscombe Down confirmed these results in 1941, and established the further result that persistent trails were practically never formed in the stratosphere but only short ephemeral ones⁷.

Cloud and fog have always had special interest for the airman by reason of their obstruction to vision. With the need to operate in all weathers, the questions of turbulence in clouds, of icing of airframes and carburettors, and of lightning have become of greater import. Various devices and also theoretical computation have been used by the meteorologist to measure or assess maximum gusts, water content, drop size distribution, etc., in clouds; and a powerful new tool has become available in recent years in the shape of radar.

Co-operation between the Meteorological Office and the Telecommunications Research Establishment of the Ministry of Supply has led to special applications of radar. It was found that some clouds, notably those containing large water drops, interfered greatly with the ordinary use of radar for detecting solid bodies. It is possible, by the use of wave-lengths of 10 cm., to locate all the important precipitation clouds within a range of the order of 70 miles from the investigating radar station. Such a radar station is now used by the Meteorological Office for experimental purposes in co-operation with machines of the Meteorological Research Flight carrying observers and with single-seaters of the Royal Aircraft Establishment. The aircraft are equipped with apparatus for recording gustiness and work, in collaboration with a simple network of ground stations, on the exploration of all aspects of cloud structure.

A series of very valuable experiments on condensation and sublimation of water has been conducted in the Clarendon Laboratory, Oxford, under the

direction of Dr. Dobson, the present Chairman of the Meteorological Research Committee. Air tests under natural conditions are made by the Meteorological Research Flight, which conducts observations regularly in clouds of various types with a view to determining their constitution (whether water drops or ice crystals) and the conditions of formation of rain and snow. Experiments in methods of "rain-making" are also being tried, not purely with the idea of causing rain to fall, but rather as a means of studying the physics of rain formation^{8,9}.

Weather forecasting.—Almost every advance in meteorology is a potential contribution to weather forecasting. Notably is this true of improved means of obtaining upper air observations, of researches on the dynamics of cyclones, the physical processes of weather and so on. Of late years other important aids have been introduced. The "Sferics" equipment¹⁰, for example, a radio receiving and direction-finding apparatus set up with the help of the National Physical Laboratory at four stations in the British Isles, can sweep all regions within some 1,500 miles and locate places where lightning is occurring. In practice, this means that many of the important regions of precipitation and beginning of precipitation can be charted.

During the war various methods of forecasting weather up to a fortnight ahead were tried, but none gave any measure of success substantial enough to justify continuation. Thus, unless in certain specially stable types of weather which may justify extension to a week, it is not yet considered justifiable to issue forecasts for more than about 24 to 48 hours ahead. The advantage to be secured from more accurate weather forecasting and from an extension of the period to a matter of weeks, still more to seasons, would be enormous, not only in military operations but in the general economy of the country. The complexities of weather as shown when it is mapped over a large area, for example the northern hemisphere, are so great that no immediate prospect can be seen of forecasting with accuracy of detail and of time scale for any long way ahead. On the other hand it may be that some method may yet emerge of outlining the broad characteristics of the weather over longer periods or of discovering in advance whether a season is likely to depart conspicuously from normal in temperature, wind distribution or rainfall, for example. Only a better understanding of the general atmospheric circulation and the factors controlling it can tell.

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ERRATUM

March 1949, PAGE 85, line 12: *for lower read higher*; line 13: *for higher read lower*

THE STRATOSPHERE

By J. K. BANNON, B.A., and A. H. R. GOLDIE, D.Sc., F.R.S.E.

The temperature of any part of the atmosphere is, though often indirectly, dependent on the energy radiated by the sun. The qualification "indirectly" is important because the temperature of the air at a particular place and time is not just a result of what is taking place there. It depends also on other factors. The first of these is its recent past history—*i.e.* it may have travelled from a place where conditions promoted higher or lower temperatures than those which it would have assumed had it always been where it is now: this is the "advective" effect. The second factor is the dynamical control of temperature through its pressure changing under more or less adiabatic conditions.

Solar radiation, being largely in the visible part of the spectrum, is but little absorbed by the lower atmosphere and is for the most part passed down through it and warms the surface of the earth. The air is thus warmed only very little by direct sunlight except at very great heights. The outgoing radiation from the earth, however, is mainly in the infra-red part of the spectrum and is strongly absorbed by three minor constituents of the atmosphere, namely water vapour, carbon dioxide and ozone. Apart from possible advective and adiabatic effects, which will be discussed later, the atmosphere can therefore be divided roughly into three layers:

(i) the lowest, the troposphere, where heating by the earth's surface is spread upwards mainly by convectional processes.

(ii) the lower stratosphere where absorption of the long-wave out-going radiation is the main controlling factor.

(iii) the upper stratosphere where absorption of direct solar radiation by ozone, mon-atomic oxygen or other constituents, controls the temperature.

Lower stratosphere.—The tropopause, the dividing surface between troposphere and stratosphere, varies considerably in height, its mean level varying from equator to pole and also from summer to winter. In the tropics it is usually to be found at heights of 16–18 Km. but towards the poles its mean height falls to 10–12 Km. in summer and to 8–10 Km. in winter.^{1,2,3*} Over this country the mean tropopause height is about 10½ Km. in winter and 11½ Km. in summer but variations from day to day are often as much as 3–4 Km. In the tropics, the lower stratosphere is cold (–70° to –80°C.) with a progressive warming towards the poles where it has a mean temperature of –50° to –60°C. in winter and –40° to –50°C. in summer.

Above the tropopause, the temperature does not vary greatly with height up to 35 Km. or so⁴, but before this height is reached, probably above 20–25 Km., direct solar radiation begins to assume importance.

As stated above, the important factor in the maintenance of the temperature of the lower stratosphere is the absorption of outward long-wave radiation by water vapour, carbon dioxide and ozone. Let us consider each of these in turn:—

Water vapour.—Reliable observations of humidity in the stratosphere are very few. Those reported by Dobson⁵ and more recent observations made by the Meteorological Research Flight⁶, using the same type of instrument

*These numbers refer to the list of references on p. 103.

the Dobson-Brewer frost-point hygrometer, have shown that over Great Britain, the air in the lower stratosphere is usually very dry, with a relative humidity of only a few per cent. Because the height attainable by the aircraft of the Meteorological Research Flight is, at present, restricted to about 40,000 ft., these observations were made mainly in air with a polar origin (low tropopause). When stratospheric air has a tropical origin the tropopause will be above the maximum ceiling of the aircraft; it may be found to be moister than polar stratospheric air, but, because of its lower temperature, it cannot hold much water vapour. It seems safe to say that, in general, the air of the lower stratosphere contains very little water vapour—probably the mixing ratio is of the order of 0.01 gm. of water vapour per Kg. of air, or the absolute humidity at the base of the stratosphere is about 3 mg./m.³ over this country.

Carbon dioxide.—Dobson, from a review of all available evidence, estimates⁵ that the concentration of carbon dioxide in the lower stratosphere is roughly constant and equal to 0.03 per cent. by volume.

Ozone.—The total amount of ozone in the atmosphere above a particular place, varies considerably. Near the equator it is small and fairly constant—equivalent to a layer 2 mm. thick at standard temperature and pressure; in high latitudes, however, there is a large annual variation, the amount of ozone being greatest in spring, when it can be equivalent to 4.5 mm. or more, and least in autumn when it is about 25 per cent. greater than the equator value⁵. In temperate latitudes the ozone amount varies greatly from day to day, stratospheric air from a polar source having much larger total amounts in the vertical direction than air from the tropics.

The concentration of ozone increases upwards in the stratosphere, reaching a maximum at a height between 20 and 30 Km. and falling off to zero by about 50 Km.^{4,5} There does not appear to be as yet an entirely satisfactory explanation of ozone formation and distribution.

Dobson⁵ comes to the conclusion that the above gases are of roughly equal importance in the radiative balance of the lower stratosphere, the relative concentrations explaining the observed differences in temperature. They each absorb the outgoing long-wave radiation. Dobson's argument is very convincing and since the annual variation of temperature in the lower stratosphere shows a maximum in June and not in August, as in the troposphere, it fits with the idea that the warming is caused by the increased absorption in spring by the greater quantities of ozone. Dynamical and advective effects may also be very important as will be seen later.

Stratosphere at greater heights.—Ozone, of course, absorbs radiation strongly in the short wave-lengths from 2200Å to 3200Å. It is quite understandable, therefore, that available evidence points to a big increase in temperature in the stratosphere above about 35 Km. where the proportion of ozone to air (by volume) is at a maximum.

Measurements by radio-sonde balloons can at present be made only up to about 30 Km. The results of careful experiments on the audibility of sound at great distances, however, can only be explained on the assumption that temperature increases above about 35 Km. This is confirmed by the fact that meteors (of all sizes) most frequently disappear at heights between 45 and 50 Km. indicating higher temperatures there than at the tropopause⁴.

Above 40–50 Km., conditions are more a matter of conjecture. Recent American observations from V-2 rockets^{7,8} indicate that the temperature distribution shows the same characteristics as that assumed in the National Advisory Committee of Aeronautics proposed standard atmosphere, up to heights of 400,000 ft., based on theoretical considerations⁹, *viz.* a maximum at about 50 Km. of 320°A., a minimum of about 200°A. at 80 Km. and a steady rise above 100 Km. It is not yet clear, however, how much reliance can be put on these measurements.

Chapman¹⁰ suggests that above the ozone levels mon-atomic oxygen, which can absorb some solar radiation, is present in increasing proportions, and this could explain the increasing temperatures at great heights.

Little is known of the variation of temperature in the high stratosphere with place and time. Murgatroyd and Clews¹¹ have found that the wind at 30 Km. over south-east England is predominantly easterly in summer, rising to some 30 m.p.h., and in winter is generally westerly, with rapid variations in direction between NW. and SW. and averaging about 100 m.p.h. at mid-winter. Murgatroyd¹², from measurements based on the propagation of sound from explosions, has found an important seasonal variation of temperature, the temperature at 45 Km. being some 40°C. warmer in summer than in winter. This kind of seasonal temperature variation is, in fact, necessary to give the pressure field appropriate to the seasonal variation in wind direction at 30 Km.

Since the absorption of solar radiation is probably all-important at great heights, it is to be expected that the position of the sun in the sky will have a great effect on temperature there. Gowan¹³ has calculated that even the diurnal variation of temperature at 50 Km. over this country should be of the order of 25–30°C., while Seaton¹⁴ estimates diurnal variations of the order of 100°C. and temperature differences of over 100°C. between polar and equatorial regions at heights above 100 Km.

Advective and dynamical effects.—A great complication is superposed on all that has been said earlier by the advective and adiabatic factors. We know that the air in the stratosphere, at the equator for example, does not stay put in that latitude. Following the Krakatoa eruption of 1883, the dust, and the optical phenomena considered to be due to its presence in the high atmosphere, gradually spread both northwards and southwards in an ever-widening belt from the equator. It crossed the 40 degrees of latitude to Japan, for example, in the stratosphere in about four days¹⁵. There must therefore be corresponding air movements.

Again, if we compute the density of the air in different latitudes at different heights, we find some interesting results. At the surface at the solstices the density in different latitudes varies by up to 10 per cent.; about 8 Km. it is comparatively constant all over the globe, varying by not more than 2 per cent. At 16 Km. it has become some 20 per cent. greater at the equator than near either the arctic or the antarctic circle. At 24 Km., so far as we can infer from the information available, the variation is again small, up to perhaps 5–8 per cent.; whilst at 40 Km. it seems probable that over the summer pole the density is some 30 per cent. greater than at the equator; and over the winter pole some 30 per cent. less than at the equator³. Thus, we must budget for considerable, if slow, circulations of air in the vertical; and as the adiabatic effect on temperature is proportional to $\Delta p/p$ it follows that

at great heights where the mean pressure is, say, 50 mb., the adiabatic effects of change of level on the part of the air become many times as important as at the surface.

Fig. 1 shows the average temperatures as deduced from observations, including acoustic experiments, or estimated, up to 40 Km. and the average height of the tropopause from winter pole to summer pole. The tropopause is drawn as a continuous line, but it will be seen that there is a very steep slope between latitudes 20° and 40° in the winter hemisphere and a steep, but less steep, slope between latitudes 35° and 50° in the summer hemisphere. In each of these regions there are, not infrequently, traces of two tropopauses, one at about 12 to 14 Km., the other at about 17 Km. The tropopause can be pictured as a wide lid (to the convective part of the atmosphere) and it looks as if the tropical part had been burst up by some 3 to 5 Km. The above picture of tropopause variation with latitude was derived from observations in western Europe, combined with those for India and Batavia. Hess³ has recently

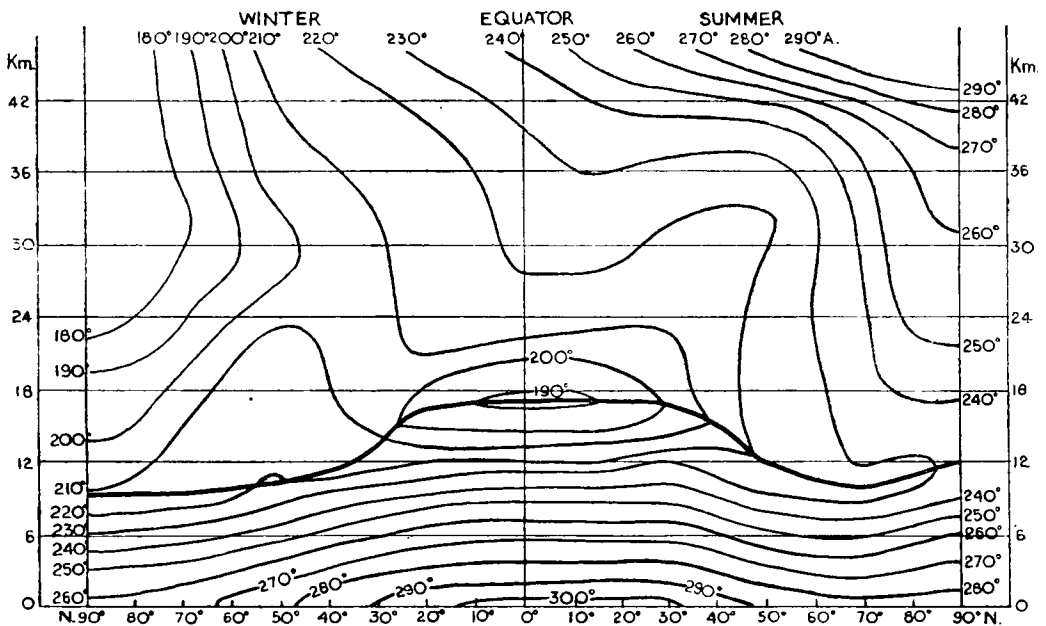


FIG. 1.—DISTRIBUTION OF TEMPERATURE WITH HEIGHT AND LATITUDE

Based on data from Abisko, England, India and Batavia. Temperatures are in degrees absolute and the tropopause is the thick line

given a cross-section derived from radio-sonde data roughly along 80° W. and covering latitudes 2° S. to 71° N. in summer and winter. A cross-section derived from his paper is shown in Fig. 2. He finds that the tropopause cross-section is not a continuous line but falls quite definitely into separate arctic and tropic tropopauses, the discontinuities or regions of overlapping tropopause for 80° W. lying in about 38° N. in winter and 50° N. in summer. The position of the breaks in the tropopause therefore doubtless varies with longitude.

Several circumstances suggest that, in these latitudes of overlapping tropopause, masses of air from the upper part of the tropical troposphere and from the lower part of the tropical stratosphere are drifting out quasi-horizontally to middle latitudes. The first pointer is a temperature and density distribution which would favour such a circulation. The next pointer is that it is difficult

to see how air could be brought to the frost points now being measured in the lower stratosphere over England without having passed at some recent time in its life history through the region of the equatorial tropopause. Note also that in these latitudes of steeply sloping tropopause the isentropic surfaces cut the tropopause.*

If this picture is correct, the air which is found in the lower stratosphere of temperate and higher latitudes is air which has come from the tropics, has subsided—as a rule by some 3 Km.—and has been correspondingly adiabatically warmed by an amount of the order of 25° or 30°C . Its temperature and its frost point are at least broadly consistent with this life history².

But if this is correct, there must be a reverse side; in polar regions or, at least near the winter pole, there should also be no continuous tropopause but a cooling and subsidence of stratosphere air into troposphere air to be followed by its eventual return, through the great eddies of depressions, to lower latitudes.

If valid, this picture of stratosphere air as having come at some earlier time, even if slowly, from tropical latitudes and piled up in temperate and higher latitudes according to the height of the tropopause, would also have a bearing on the amount of ozone found at any time in the vertical direction—but that is too complex a matter for discussion here.

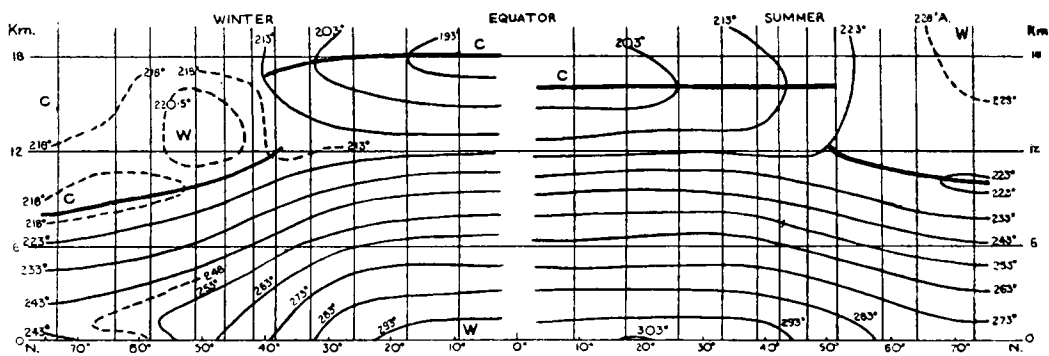


FIG. 2—MEAN DISTRIBUTION OF TEMPERATURE ALONG 80°W . MERIDIAN³
Upright lines indicate stations whose observations were used in drawing the cross-section.
Temperatures are in degrees absolute and the tropopause is the thick line. C = cold region;
W = warm region

When we look more closely at the pattern of the tropopause over the globe we see that, on top of this broad difference of level according to latitude, there are dimples over the cyclones, where the tropopause seems to be pulled down and it is warm, and humps over the anticyclones, where the stratosphere is pushed up and it is cold. To a large extent these local variations can be explained by advection of air masses complete with their stratospheres from higher or lower latitudes¹⁶. But there is an intimacy of association with surface pressure distribution which suggests a dynamical connexion; and it is possible to show in particular cases that variation of level of tropopause exists over an air mass which is homogeneous as to its origin.

A number of years ago, V. Bjerknes¹⁷ showed that, if two superposed fluids of different densities with a quasi-horizontal bounding surface are in steady rotation, the boundary surface is pulled down or pushed up according as the

*See, for example, Fig. 2 of Goldie's paper² or Fig. 63 of "Manual of Meteorology", Vol. II.

kinetic energy of rotation is greater in the lower or the upper fluid. Now recent preliminary investigations¹⁸ using radio-wind measurements suggest that, at least in the later stages of a depression's life, the kinetic energy reaches a maximum in the upper part of the troposphere. The result should thus be to pull down the tropopause and incidentally, by the same reasoning, to pull up the boundary between warm and cold air (*i.e.* to occlude the depression); whether it always works out in accordance with theory and whether it works for anticyclones remains to be investigated. But, if we accept the dynamical explanation for cyclones, may not the same principle determine in a broad way the variation of tropopause height from subtropical latitudes up to the poles? Here we have a belt of more or less strong westerly circulation increasing with height in the troposphere and falling off rapidly again in the lower stratosphere. This general westerly circulation, regarded as a vortex about the poles, thus has as a rule its maximum kinetic energy under the tropopause and the result should be to pull down the tropopause towards high latitudes.

It seems that both the dynamical and the advective effects are essential and fundamental parts of any explanation of the variations of tropopause height with time and place. It is not conceivable that any theory of radiative balance could alone explain the day-to-day changes in tropopause level and stratosphere temperature which take place in temperate latitudes and their continual adjustment to the synoptic situation. The extreme range of these changes is not much short of the whole range of conditions experienced over the whole globe.

Summary.—The picture, finally, of the stratosphere which we are tempted to give is thus one in which the quasi-static conditions at the “boiler” of the atmospheric heat engine are determined by radiation in the tropical zone, and the conditions (probably also quasi-static) at the “condenser” of the engine are determined again by radiation in polar regions—probably mainly in winter polar regions; whilst in the latitudes between, where the air is changing position more rapidly, dynamical and advective processes play a large part in adjusting the shape of the boundary surface between stratosphere and troposphere and in determining (adiabatically) the temperature within the stratosphere itself.

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SCIENTIFIC RESULTS OF THE "BALAENA" EXPEDITION 1946-47 Meteorology

BY H. H. LAMB, M.A.

Two earlier articles have given a general account of the meteorological work on the 1946-47 *Balaena* expedition to the eastern Antarctic whaling grounds in the Southern Ocean^{1*}. The present article is intended to give a summary of the scientific results of the expedition in the field of meteorology pending the full report, publication of which may unavoidably take some time.

Surface weather observations were carried on from leaving England in mid October 1946 until the vessel's return to Southampton in May 1947. The observations were made at 6-hr. intervals in the Southern Ocean, for the most part between 80° and 115°E. and between 55° and 65°S. close to the ice margin. A full weather diary covered progressive changes of weather and cloud development in the intermediate hours. 105 pilot-balloon ascents were made at picked times when the 15,000-ton vessel and her course and speed were steady enough to permit the use of theodolite and tripod (see photograph facing p. 108). In 1946 no special marine theodolite was available, but the method used was checked in various ways and found to give satisfactory results. Ninety ascents were made in the Southern Ocean, the remaining fifteen in the South Atlantic and near the equator on the homeward voyage; the highest ascent reached an assumed height of 57,000 ft.; and altogether fourteen balloons were followed to heights above 10,000 ft. over the Southern Ocean. In addition, *Balaena's* aircraft made twelve meteorological ascents in the Far South, using psychrometers supplied by the Meteorological Office (see photograph between pp. 108 and 109); several of these ascents reached 10,000 ft. To send up radio-sondes would have taken more time, labour and accommodation than was available, but even so a valuable amount of observational data was brought back from regions where little meteorological work had been done before.

The quotation of averages and statistics from the observations of one moving ship visiting various regions in the course of a single southern summer and autumn can have little meaning, unless great care is exercised in the manner in which data are grouped and considered. We shall prefer therefore to present

^{*}These numbers refer to the list of references on p. 112.

particular observations of special interest and to point to what appear to be significant trends. This scruple has guided the entire work and will be followed here.

Upper air observations.—A deeper troposphere than has been commonly supposed to occur in the Far South was indicated by a pilot balloon entering cirrus cloud at 43,500 ft. near 59°S. 81°E. on December 28, 1946. Comparable observations have since come to hand in the radio-sondes from the Dutch whaling ship *Willem Barendsz*, mainly south of 60°S. in the Atlantic sector, during the same season, though these would suggest that the tropopause is somewhat lower on most days.

Low cloud limited pilot-balloon work in the stronger easterly winds, hampering efforts to explore the depth of the easterly current. Table I however gives extracts of some *Balaena* ascents which are of interest in this connexion. Although the easterly components generally decrease upwards, this is not so in all cases: the balloon of January 18, 1947 showed increasing south-easterly wind up to 134° 36 kt. at 13,000 ft., the greatest height reached. This was the

TABLE I—SAMPLE PILOT-BALLOON ASCENTS FROM THE *Balaena* IN EASTERLY WINDS

Date	Time	Position		Winds at heights of							
				2,000 ft.		5,000 ft.		10,000 ft.		20,000 ft.	
	G.M.T.	°S.	°E.	°true	kt.	°true	kt.	°true	kt.	°true	kt.
3.12.46	1600	59·9	66·8	223	5	049	2	068	3	—	
28.12.46	1200	59·2	81·3	036	11	046	19	006	10	274	19
29.12.46	1100	59·5	81·8	069	16	103	15	047	15	—	
18. 1.47	1100	63·3	94·6	171	21	186	20	153	25	—	
27. 1.47	1400	63·3	98·5	098	5	050	4	260	4	195	3
7. 2.47	1000	64·3	105·9	081	14	084	12	030	2	—	
22. 2.47	0500	64·9	109·6	075	15	078	7	142	6	—	
5. 3.47	1100	65·1	112·9	127	21	152	15	089	7	—	
12. 4.47	0800	63·0	43·9	023	17	027	14	259	17	—	

deepest, so-called “solid” easterly current probed. The prevailing westerly currents of the upper levels of the troposphere were however distorted or replaced by southerlies and northerlies on a number of occasions; and it is clear that when the wind in the lowest layers was easterly the currents between 10,000 and 20,000 ft. were commonly light airs from various directions.

The highest-level wind observation of all was 166° 14 kt. at 55,000 ft. on January 24, 1947 in 63½°S. 97½°E. This was in an anticyclonic situation with light southerly and south-westerly winds in the lower levels. There were several progressive changes aloft in this ascent: to 268° 9 kt. at 14,000 ft., to 153° 19 kt. at 28,000 ft. and to 280° 22 kt. at 41,000 ft.

Samples of typical deep westerly currents are given in the ascents listed in Table II, including one in 65°S.

TABLE II—OCCASIONS OF DEEP WESTERLY CURRENTS

Date	Time	Position		Winds at heights of							
				2,000 ft.		5,000 ft.		10,000 ft.		20,000 ft.	
	G.M.T.	°S.	°E.	°true	kt.	°true	kt.	°true	kt.	°true	kt.
16.12.46	0800	57·1	83·8	223	15	223	16	219	17	—	
7. 1.47	1100	59·4	84·7	290	18	305	21	265	22	—	
7. 3.47	0900	65·0	112·5	264	6	311	9	318	20	321	24

The continuous series of 156 daily weather maps drawn on the *Balaena* during the season suggest how these upper air observations may be related to the synoptic circulation patterns of a great part of the southern hemisphere.

In Fig. 1 sample upper air temperature soundings, made by *Balaena's* Walrus aircraft under the command of John Grierson are shown. The ascent on February 11, 1947 was made in a deep westerly current in high latitudes, the centre of lowest pressure being estimated over Wilkes Land in $65\text{--}70^\circ\text{S}$. $125\text{--}130^\circ\text{E}$.; the lapse rate approaches the saturated adiabatic in the surface air mass up to 8,500 ft. The ascents on March 8, 1947 were made in a stagnant situation with presumed antarctic continental air over open water close to the coast in $114\text{--}116^\circ\text{E}$.; instability was indicated by the growth of towering cumulus and altocumulus castellatus clouds, with tops in sight probably reaching 20,000 ft. over the coastal mountains. The sky looked thundery—this being the only occasion during our sojourn in high southern latitudes—although most of the cloud had a high base and no thunder was heard. Small hail fell in a brief shower over the ship. Another type of situation is represented by the ascent of March 15, 1947, with south-westerly winds and a ridge of high pressure thrusting out from Antarctica; the stable layer and clear sky above the stratocumulus top at 2,000 ft. probably indicate subsidence.

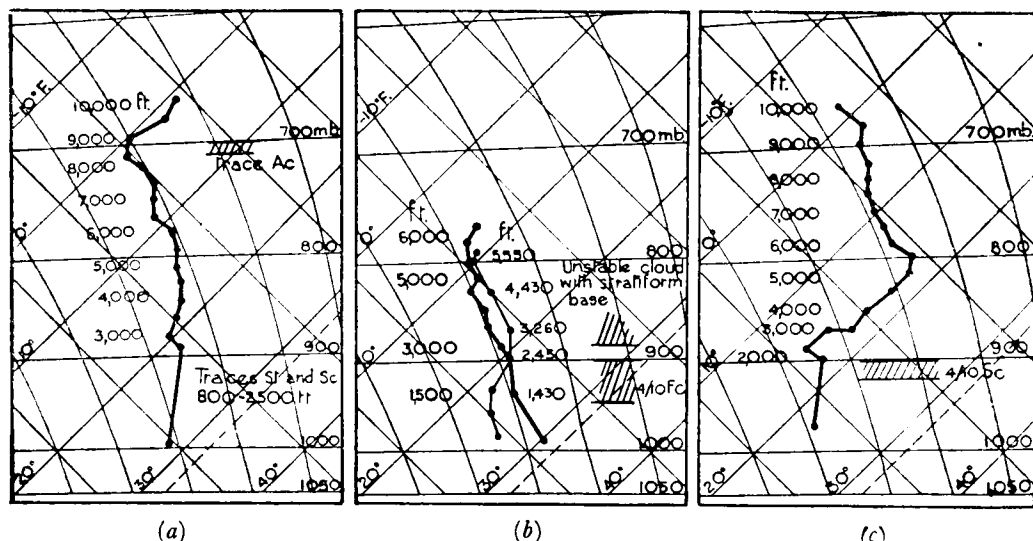


FIG. 1.—TEPHIGRAMS OF AIRCRAFT OBSERVATIONS IN THE SOUTHERN OCEAN

Observations were usually made at 500-ft. intervals

- (a) in $64.5\text{--}65^\circ\text{S}$. 109°E . at 0430 G.M.T., February 11, 1947;
- (b) in 65.3°S . 113.8°E . at 0540 G.M.T., March 8, 1947 (thick line) and in 65.7°S . 116.2°E . at 0650 G.M.T., March 8, 1947, in clear patch with towering cumulus further east (thin line); and
- (c) in 64.3°S . 106.3°E . at 0830 G.M.T., March 15, 1947.

These ascents dispel the idea that we can speak of a prevalent surface inversion over the cold waters of the Far South, at any rate in the sector visited, even in summer. Subsidence inversions between 2,000 and 4,000 ft. were usually indicated in fine weather; at other times unstable air masses often separated by thin, stable layers were common.

Surface weather observations.—Cumulonimbus and large cumulus cloud, already referred to, were observed on 35 out of 150 days south of 50°S .

Alto cumulus castellatus was very rare. Stratocumulus clouds prevailed, often with small cumulus penetrating the base. Normal frontal altostratus, alto cumulus and cirrostratus were often seen. In the "fifties" these systems advanced mainly from west and south-west, but farther south frontal cloud systems advancing from other quarters, notably from east and south as well as north, became frequent.

The mean of all *Balaena's* pressure observations in five months south of 50°S. was 982.2 mb. This is consistent with the generally low level of pressure represented by all available annual mean pressures south of 50°S., though rather lower than any of the known annual means (the lowest being 986.5 at Mawson's Queen Mary Land base, near the coast in the same sector in 66°S. 95°E.*). During the 1946-47 season another whaler *Empire Victory*, operating around 63°S. 84°E. over a more restricted area than *Balaena*, had a mean pressure of 985 mb. for 4 months. Now all the available reports during the same period in other sectors, including some from whaling ships in the Weddell Sea, show values close to the known annual means (*i.e.* within 2 mb.). These figures suggest therefore that our annual mean pressure maps should show a centre of lowest pressure in the Indian Ocean sector. Fig. 2 shows a suggested scheme of annual mean pressures covering the southern hemisphere, using all the previously existing data and amplified in the light of these indications.† The pattern over Antarctica follows Meinardus³ with slight adjustments suggested by the *Balaena* daily weather maps.

It is interesting to note that pressures observed even in good weather in extensions or offshoots of the antarctic anticyclones over the surrounding ocean were low by comparison with northern hemisphere experience, ranging from 988 mb. to about 1010 mb.—the latter figure coming from the Weddell Sea region. *Balaena* only once had pressure over 1000 mb. south of 60°S., 1002.4 being observed near 63°S. 96°E. on January 24, 1947.

These figures hint at an unequal division of atmospheric pressure between the northern and southern hemispheres as a whole. The explanation probably lies in the recurrent strong westerly currents blowing over the main width of the Southern Ocean and always ready to break down any tendency to establish a large-scale meridional transport of air. Nevertheless we have seen that meridional transport does sometimes occur even at great heights, and it is suspected that the anticyclones over the south polar plateau depend upon occasional instances of such transport for their formation. The composite picture of atmospheric circulation which this implies suggests that the manner of formation of the antarctic continental anticyclones is similar to that of anticyclones in high northern latitudes and yet explains why they seldom reach the intensity of their northern counterparts.

The surface air temperatures observed by *Balaena* require little comment. The average of all observations south of 50°S. was +28.7°F., extremes being +37.8°F. and +12.1°F.

Relative humidities varied from 100 to 55 per cent., values of 65-70 per cent. being typical in fine weather. Fog was not common, and occurred at only 15 out of 600 observations south of 50°S.; in this respect it is thought that the

*The German expedition ship, *Gauss*, had a mean pressure of 986 mb. over 11 months, when she was icebound near 66°S. 90°E., also in the same sector.

† *cf.* Maps in Shaw's "Manual of Meteorology".²

eastern longitudes visited by *Balaena* differed from certain other sectors. For instance, fogs are believed to be commoner in the South Atlantic sector east of the Weddell Sea. In the Indian Ocean sector, according to certain indications, fogs are relatively commoner in longitudes 80–90°E. than farther east.

Air-mass advection fogs are noticeably associated with winds with northerly components—even slight northerly components—bringing warmer air streams over the cold water. This generalization seems to apply to widespread fogs in all sectors in high latitudes in the Southern Ocean and is familiar to the whalers.

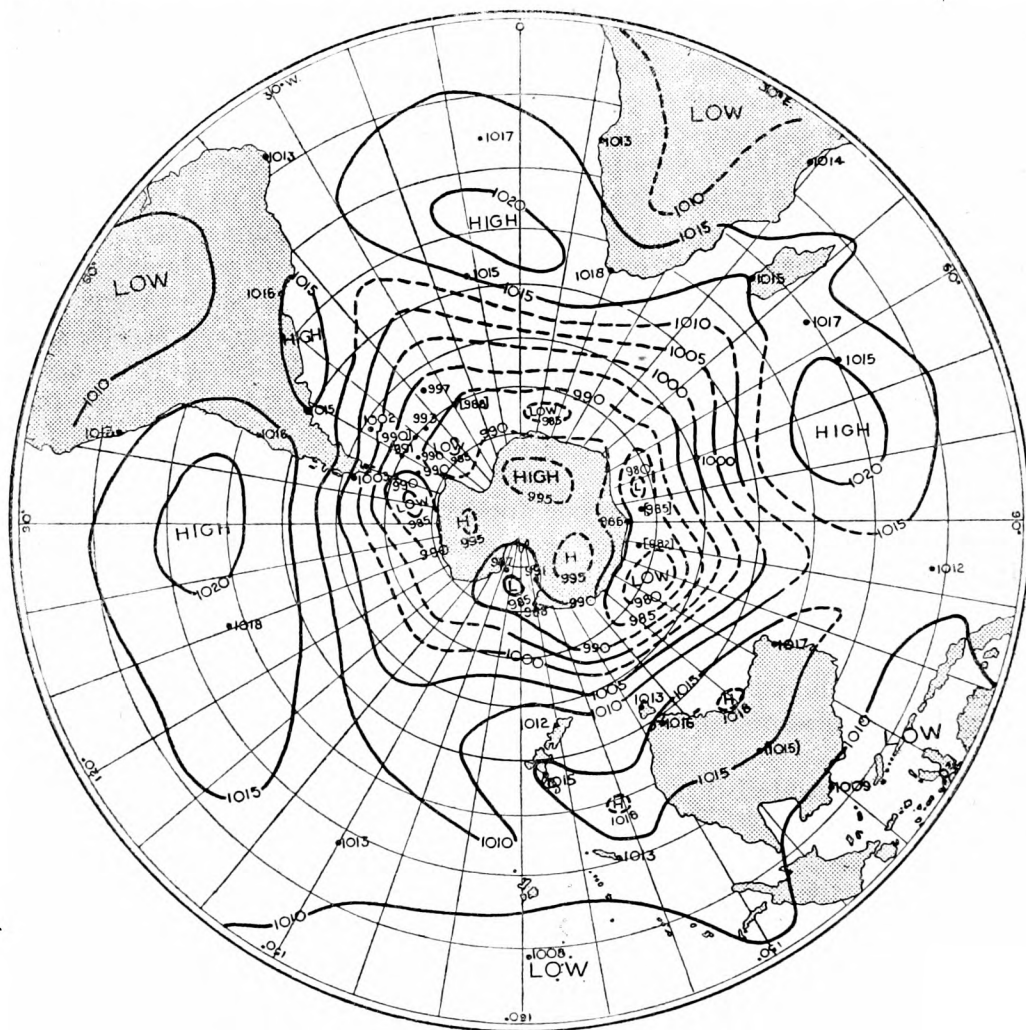


FIG. 2—SUGGESTED ANNUAL MEAN PRESSURE PATTERN

Figures in square brackets taken from the 1946–47 whaling vessels' observations, using these figures as indicative of the probable yearly values over the same parts of the Southern Ocean.

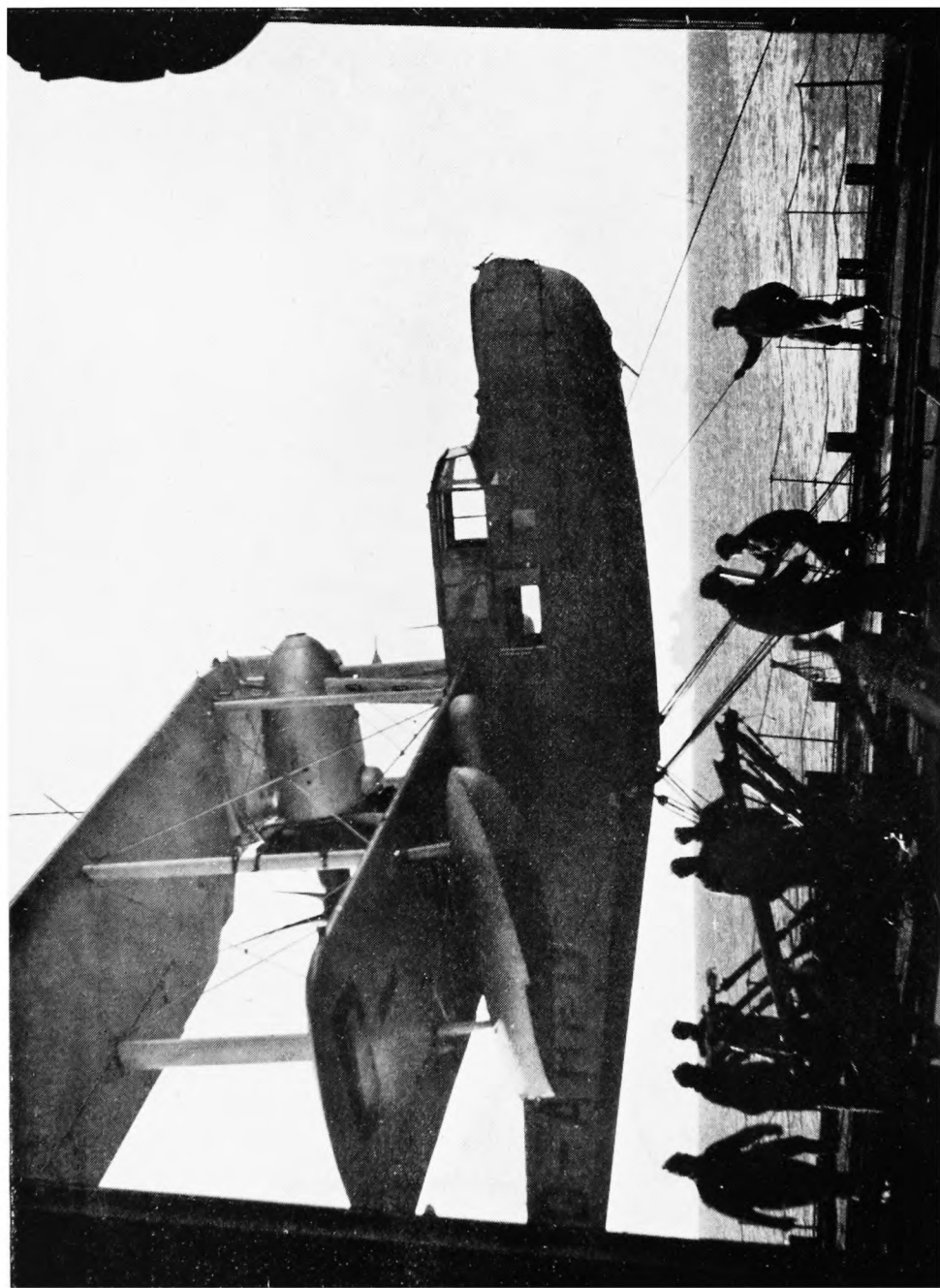
Most of the fogs experienced in the *Balaena* voyage in the Far South were however frontal fogs, in narrow and very isolated belts, and these might persist for some time even when drifting slowly from south to north. These frontal fogs, believed to be associated with increased humidity in the lowest layers where precipitation was, or had been, falling, were accompanied by residual frontal cloud sheets, attributed in most cases to old, decaying occlusions drifting about in, or driven forward by, the circulations of newer systems.



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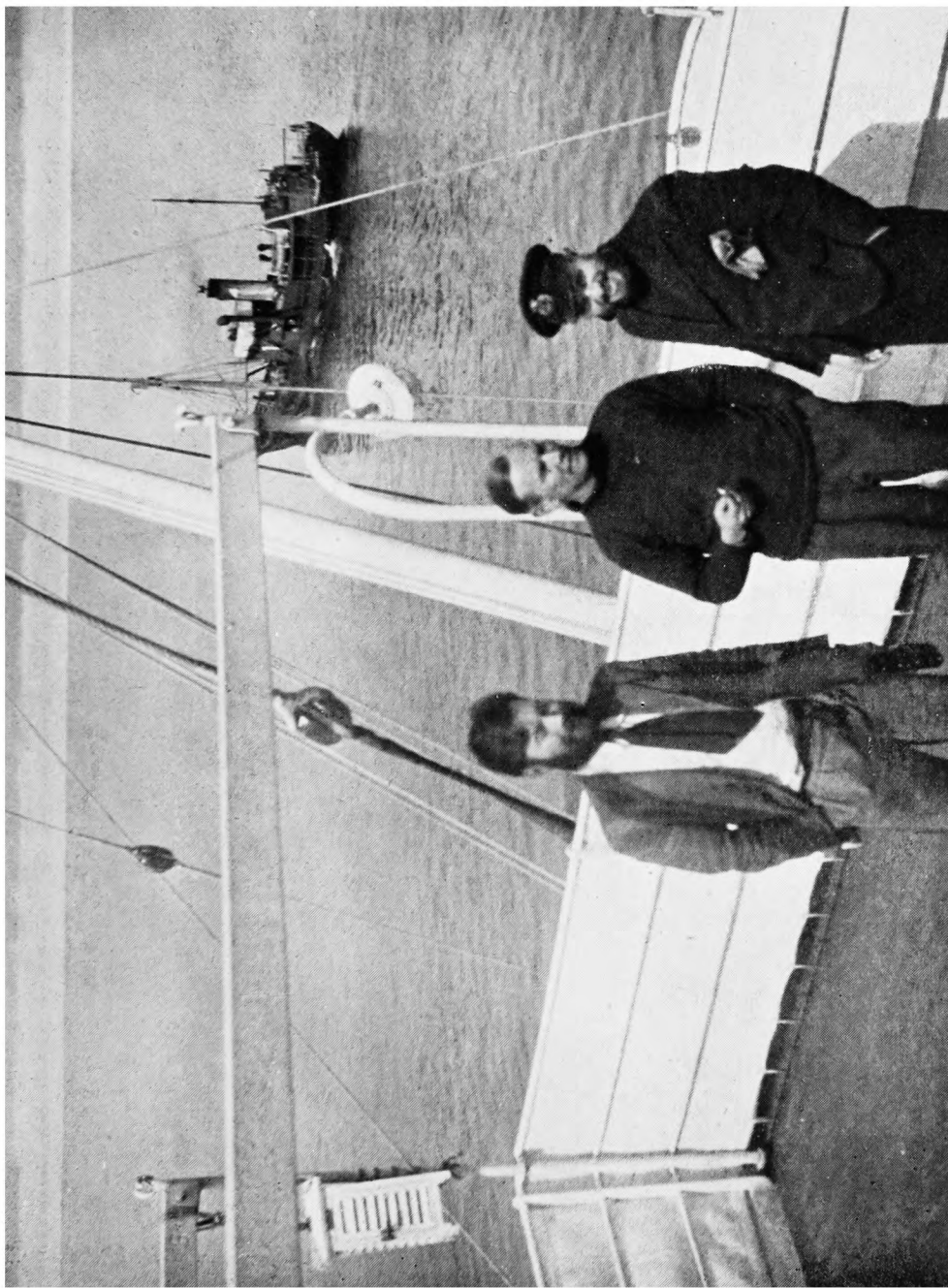
THEODOLITE SET UP FOR A PILOT-BALLOON ASCENT ON THE FLIGHT DECK AT *Balaena's* STERN

Such a large balloon (rising at 1,000 ft./min.) was used in exceptionally good conditions. The flight deck is 45 ft. above the water line. Two small icebergs can be seen near the horizon at the left. (see p. 104)



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MANŒUVERING THE WALRUS AIRCRAFT ON TO THE CATAPULT TROLLEY AT *Balaena's* STERN
The catapult was fired so that the aircraft was sent out abeam. The psychrometer can be seen close to the fuselage just at the afterside of the lower window which was used by the observer. Two icebergs can be seen on the sky-line.
(see p. 104)



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EXPOSURE OF THE THERMOMETER SCREEN 60 FT. ABOVE THE WATER LINE

Screens were suspended above the forward rail of the Monkey's Island, on either side of W/F Balaena, and the windward screen used for readings. The whale-boat in the background is towing a whale alongside.



Reproduced by courtesy of H. H. Lamb

RAIN-GAUGE AND ROPE CRADLE USED FOR HOISTING TO THE YARD-ARM

One gauge was suspended on either side of the foremast. This thick deposit of rime occurred during 24 hours exposure to fog and had to be chipped off the suspension before the gauge was hoisted again. (Fog was not common, but the occasional instances produced deposits of ice in quantities of similar order to the precipitation received in the form of snow, drizzle, etc. in high southern latitudes.)

Cloud amounts averaged over 9 tenths in most sections of *Balaena's* voyage south of 50°S., but fell to 7·4 tenths in the narrow sector between 105° and 110°E. where the ship was fairly close to the coast of Antarctica and had more off-shore winds. Yearly averages of 5–6 tenths are typical for cloudiness reported at expedition stations on the Antarctic coast in eastern longitudes. In the “fifties” in the Indian Ocean away from the pack-ice appreciable amounts of clear sky seemed only to occur in regions of strong subsidence between frontal systems; even so, totally clear sky was never observed, the next advancing cloud system always coming into view before the last had disappeared. In those regions sunshine was therefore confined to periods of 3 or 4 hours once in 4 or 5 days. Cloudless skies did occur however in off-shore winds sufficiently near the ice-margin or coast of Antarctica.

The instrumental equipment on *Balaena* included two Snowdon rain-gauges, which were not however found suitable for measuring precipitation in the Far South without considerable adaptation. Measurements were fairly successful, using modified gauges in different exposures for purposes of comparison from November until mid February, but thereafter (when the season became stormier) had to be eked out by estimations. During the 5 months spent south of 50°S. the estimated total equivalent rainfall was only 43·6 mm., roughly equivalent to 105 mm. or 4 in. of rain a year. Comparable figures have been obtained from stations in the Australian desert, the Sahara and near the coast of northern Greenland. This low rainfall total represented slight, though frequent, precipitation; only one day in five was free from rain or snow. Moisture precipitated by the comparatively rare fogs on the vertical rigging and sides of the ship added up to a similar figure (53 mm. in 5 months), whilst a total of 4·7 mm. of glazed ice was deposited in this way even on level objects—these figures are not included in the ordinary rainfall measurements.

Wind was measured by a cup anemometer exposed above the hangar roof astern, 70 ft. above the water line. A highest gust of 56 kt. was noted, on February 25, 1947 near 65°S. 113°E. At the same time the wind was averaging 48–50 kt. and SE. force 11 was reported. The steadiness, or relative freedom from gusts, of this south-easterly storm near the coast of Antarctica was remarkable, and the ocean swell was not great owing to the short fetch of open water. Vessels at sea are of course less liable to extreme winds than stations on land exposed to katabatic gales, especially in valleys. Points close to a mountainous coast seem most favourable for extreme winds at sea; this generalization fits the *Balaena* observations and the experience of other vessels, particularly in the Ross and Weddell Seas.

Storms were not very frequent, Beaufort force 8 or over being reported at only 16 out of 600 observations south of 50°S. on *Balaena's* voyage. The mean wind force observed over the same waters was only 3·9. It is interesting to compare the annual means given by the *Gauss* station in 65°S. 90°E. in the belt of easterlies (3·5) and by Kerguelen island in the zone of Brave West Winds near 50°S. 70°E. (5·0), each taken from one year's observations. It appears that the easterlies near the coast of Antarctica in this sector are on the average less strong than the westerlies over the ocean farther north, although occasional extremes may be experienced near mountainous stretches of the coast.

An attempted geographical analysis of *Balaena* and *Empire Victory's* statistics of wind observations south of 62½°S. between November 1946 and April 1947

suggests that the pressure patterns prevailing may also favour stronger winds and rather different mean directions in different longitudes. Table III summarises the evidence. It will be noticed that the prevalent wind directions follow the broad configuration of the coast and become more variable west of 90°E., where the vessels were farther from land owing to the great bight in the coast of Antarctica between 55° and 90°E. Westerly and north-westerly winds made up over 10 per cent. of the observations in these longitudes and were distinctly less frequent though never entirely absent east of 90°E. Northerly and north-easterly winds were almost lacking in the observations east of 100°E.

These observations agree with other indications that near the coast of Antarctica, longitudes east of 110°E. as far as 120° or 130°E. and east of the point of Enderby Land between 55° and 75°E. are particularly associated with strong south-easterly winds and frequent storms, whilst the sector between 80° and 105°E. gets more quiet weather.

These considerations, based partly on the experience of the whalers in other seasons, have been taken into account in drawing the suggested mean isobars in Fig. 2.

TABLE III—WINDS OBSERVED SOUTH OF 62° 30's.

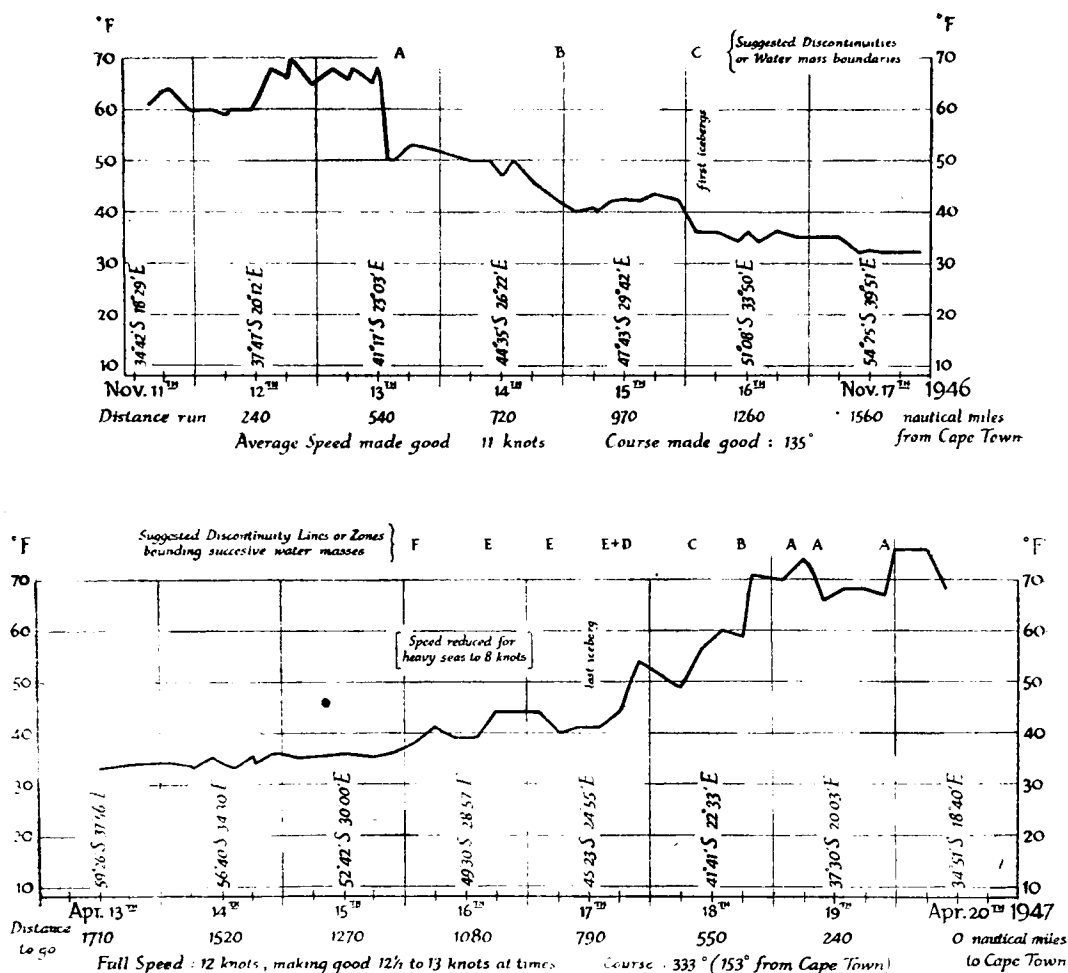
Limits of longitude	Mean Beaufort Force	Percentage of occasions from direction									No. of observations
		N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	
°E.											
115-110	5.0	3	4	24	51	7	3	4	3	3	74
110-105	4.1	0	1	21	27	14	21	12	4	0	79
105-100	3.2	3	6	25	25	3	19	9	6	3	33
100-95	3.6	2	8	24	37	19	12	0	0	0	67
95-90	3.4	0	12	38	26	11	11	3	0	0	86
90-85	3.7	10	14	19	15	11	14	8	8	1	73
85-80	3.5	9	15	24	12	11	12	12	5	0	102
80-75	3.7	3	5	21	16	11	21	8	14	0	37
75-70	(5.5)	0	6	12	29	18	24	12	0	0	(17)

Other observations.—Fig. 3 presents the sea temperatures observed on the outward and homeward voyages across the Southern Ocean between Cape Town and the whaling grounds. Identification of the classical temperature discontinuities known as the subtropical and antarctic convergences from these observations would be difficult; the curves suggest rather a variable situation with three well marked discontinuities passed on the southward voyage in November and no major but several minor discontinuities on the return voyage in April.

Between March 3, 1947 and April 12, 1947 *Balaena* travelled rather quickly west along the ice margin, giving some approach to a synoptic view of the course of the limit of open water at the end of the warm season in the Indian Ocean and Australian sectors. Open water extended to the coast of Antarctica in 116°E.; from there the ice margin ran approximately north-west as far as a great ice headland in 62½°S. 101-102°E. West of this open water extended gradually farther south again, reaching south of 64°S. between 60° and 80°E. It is clear that open water extended farthest south in the stormiest regions; and it is thought that the accumulation of ice near the 100th meridian marked a transition or boundary region in both air and water circulations between the broadly cyclonic, clockwise systems of the southern Indian Ocean and those farther east.

Space forbids comment here on the other oceanographical observations.

Land was observed on a number of occasions, and observed cloud-height was used to gain an approximate idea of the heights of the uncharted mountains. Speculations about the geography of the coast and interior based upon reasoning from the meteorological observations have been discussed elsewhere.⁴



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FIG 3. SEA TEMPERATURES RECORDED WHILE CROSSING THE SOUTHERN OCEAN

Another by-product of the immediate meteorological work of the expedition has been a consistent series of daily synoptic weather maps covering a very wide area of the southern hemisphere for over 5 months. Verification of the charts in the light of observations in high latitudes in the Southern Ocean received later gave a probable error of ± 6.8 mb. in pressure and 150–190 miles in the positions of major systems. In the South Atlantic a probable error of under 3 mb. was obtained. These charts have been used as the basis of a more precise re-analysis study of an Antarctic anticyclone, for a preliminary investigation of the formation of easterly storms over the southernmost parts of the Southern Ocean, and to derive a tentative frequency distribution map of the occurrence of fronts in the southern hemisphere.

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METEOROLOGICAL OFFICE DISCUSSION

Turbulence in clear air and in cloud

The Discussion on Monday, January 31, 1949 was devoted to a symposium on turbulence in cloud and in clear air. The opening speakers were Mr. J. K. Bannon and Mr. R. F. Jones.

Mr. Bannon, in introducing the subject "Turbulence in clear air", said that for several years now it had been known that aircraft may encounter bumps in clear air even in the stratosphere. With the possibility of future aircraft flying well above 20,000 ft. and at high speed, the occurrence of turbulence at these heights is of importance both in the design of aircraft and also to planners who have to consider the comfort of passengers, a very important aspect. He intended, however, to talk mainly about the meteorological conditions associated with the occurrence of aircraft bumps at heights greater than 20,000 ft.

Regarding the severity of the clear air bumps experienced above 20,000 ft., the largest acceleration recorded was about 0.7g (the aircraft was flying at about 230 kt. equivalent airspeed) but usually the accelerations on an aircraft flying at about 180 kt. were 0.1 to 0.2g (bumps of 0.25g would be uncomfortable if they persisted and of 0.5g would be very uncomfortable indeed).

Many pilots have commented on the contrast between these bumps and those experienced near the ground on a warm afternoon; the clear-air bumps are more regular in character—almost periodic, about 2 to 3 a second—though they often occur in patches with quiet conditions between.

This high-level bumpiness has been noted above practically all kinds of weather as experienced on the ground. It has been observed in the stratosphere though it appears to occur less frequently there than in the troposphere. The highest observation of turbulence was at 42,000 ft. over Derby—6,000 ft. above the tropopause.

The bumpy layer is frequently very shallow, an important consideration for the aviator, for it means that if bumpiness is encountered it usually requires only a small change of height to get out of the turbulence.

Attempts have been made to correlate the occurrence of turbulence above 20,000 ft. with the shear of wind with height, the lapse rate of temperature with height (or static stability) and the Richardson number, but so far without success. One of the British European Airways (B.E.A.) investigational flights suggested wind shear in the horizontal as a possible factor and this has been explored further. Fig. 1* shows the ratio of the frequency of occurrence of various horizontal shears in bumpy conditions (for bumpy layers of more than 4,000 ft.

*Taken from *Met. Res. Pap., London*, No. 436.

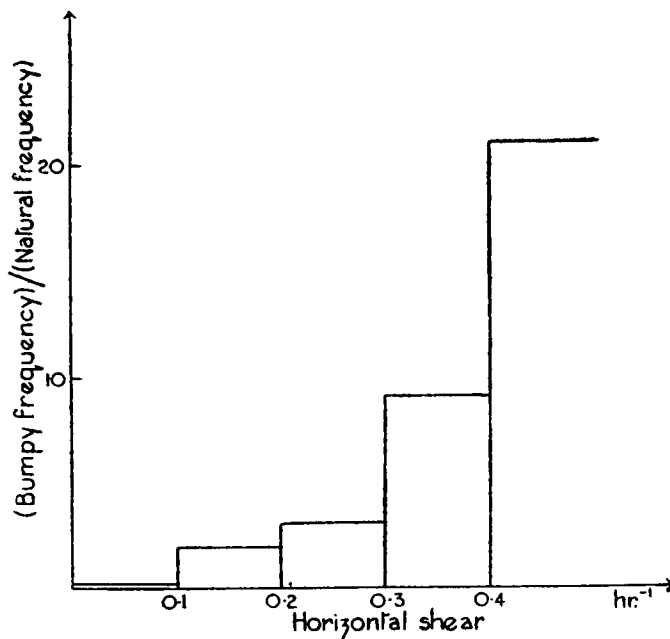


FIG. 1—FREQUENCY OF OCCURRENCE OF VARIOUS HORIZONTAL SHEARS IN BUMPY CONDITIONS (for bumpy layers more than 4,000 ft. deep)

in depth) to the average frequency of these horizontal shears for all occasions, *i.e.* the normal frequency. The fact that this ratio is not unity but increases rapidly with increasing shear, indicates that bumpiness and horizontal shear are related. A similar but less well marked relationship is found if all bumpy layers, including shallow layers, are considered.

It was also found that wind speed is related to the occurrence of high-level turbulence. Since large horizontal shear of wind is usually found on occasions of strong wind, this is not surprising. It is not certain which is the active factor, shear or wind speed, but it is much easier to visualise a physical connexion between turbulence and shear than between turbulence and wind strength.

Tentatively, therefore, it is to be expected that bumpiness will be a possibility in regions of large horizontal shear. Very strong horizontal shear is found on the boundaries of well marked jet streams, and the same characteristics of a marked maximum of wind speed at a height usually between 30,000 and 40,000 ft. are to be found in connexion with any well marked front in temperate latitudes and moving, to a certain extent, with the front. The axis of the jet or wind maximum is usually some 400 to 700 miles ahead of a warm front and somewhat less than this behind a cold front. These considerations might be used in a first tentative attempt to forecast bumps at high altitude.

An important point which seems quite well established from the data so far analysed is that bumpiness frequently occurs at or just above the tropopause. Usually it is very slight in magnitude, but not always so (the Meteorological Research Flight has on two occasions encountered quite rough conditions there). Turbulence has also been observed at and in temperature inversions in the upper troposphere. It is puzzling to find this turbulence in conditions which are very stable statically and it is difficult to conceive of vertical turbulent currents in such stable layers. The suggestion is therefore made that the bumps

experienced by an aircraft in such turbulence are not caused by vertical eddy currents, but by turbulent variations in the horizontal wind. Mr. Morris of the Royal Aircraft Establishment (R.A.E.), however, says that other evidence indicates that variations in the horizontal wind are unlikely to cause anything more than very slight bumps, and that the effect of such turbulence would decrease with increasing speed of the aircraft.

In conclusion, horizontal shear of wind is so far the only physical quantity which shows a direct connexion with the occurrence of bumps. It is likely, however, that the complete answer to the problem will be found to depend on wind shear in the vertical and in the horizontal, linked with the thermal stratification of the atmosphere, both in the vertical and in the horizontal. With the British European Airways' experimental flights continuing and valuable data being collected from R.A.F. flights, it is hoped that much more progress can be made towards the solution of the problem.

Mr. R. F. Jones opened the section of the discussion dealing with turbulence in cloud by emphasising that the investigations into this subject so far made had been confined to turbulence in cumulus and cumulonimbus clouds.

He then indicated how the work being done at the Meteorological Office radar station at East Hill was being used to investigate the problem. It is possible to distinguish, on the radar display tubes, the weather echoes from shower clouds and thunderstorms from those caused by other types of precipitation and it was therefore worth-while to investigate the possibility of using the radar characteristics of a cloud in relation to turbulence as a substitute for the visual characteristics which have been used in the past. The radar has the advantage over visual aids that it is unaffected by darkness or the presence of intervening clouds.

The radar echo from a cumulonimbus cloud does not come from the whole cloud but only from that part of the cloud which contains drops in sufficient numbers and of a large enough size. The radar echo from one raindrop is equivalent to that from millions of cloud particles. It was necessary therefore to attempt to establish whether the radar echo was the most turbulent portion of the cloud and, if so, whether there were any characteristics of the weather echo which would give an indication of the degree of turbulence to be expected and the places within the echo where the turbulence would be expected to be most marked.

Arrangements were made for a Spitfire aircraft to investigate weather echoes under direction by radio-telephone from East Hill. The Spitfire carried a recording accelerometer and was so directed that it flew always along the line of the radar beam from East Hill, with the result that a vertical cross section of the weather echo was obtained at the same time as the aircraft flew through the echo. Photographs of the radar echo were taken and accurate notes of the time of entry into and departure from cloud and weather echo were made. The readings and photographs taken at East Hill are being compared with the analysed accelerometer records. This analysis is still going on and any results given are to be regarded as tentative only and subject to revision or modification.

A total of 136 separate flights through cumulus and cumulonimbus clouds had been made involving a distance flown in cloud of some 700 miles. The magnitude and frequency of bumps encountered on each of these flights have been measured and provide a large amount of interesting data.

In dealing with these data two approaches are being made: (i) statistical, and (ii) a detailed examination of particular flights through an echo.

Mr. Jones dealt first with the statistical approach. A slide was shown which indicated that, in general terms, the higher the echo extended above the freezing level the greater was the value of the maximum up-gust likely to be recorded on flying through the cloud containing the echo. A similar analysis for down-gusts, however, showed that, for a large range of vertical extent of the echo, the maximum down-gust appeared to be independent of the vertical extent and only in clouds containing the very biggest echoes was a down-gust experienced greater than those experienced in cumulus clouds giving no echo at all.

A second statistical investigation showed the frequency with which gusts of specified magnitude were likely to occur, and a significant increase in frequency was shown to occur when the flights were made through clouds containing echoes which extended 9,000 ft. or more above the freezing level.

Although the Americans, working on a much greater volume of data, had indicated a zone of maximum turbulence at the freezing level it had not been possible to discover any such zone in the data provided by the Spitfire flights. The American flights, however, had never exceeded the freezing level by more than about 9,000 ft., while the biggest gust during all flights by the Spitfire was experienced at 30,000 ft., almost 20,000 ft. above the freezing level. There was no obvious evidence of a zone of minimum turbulence, although in the level 2,000 to 4,000 ft. above the freezing level no gust greater than $\pm 0.7g$ had been encountered, this value having been exceeded at all other height intervals.

Mr. Jones then turned to a discussion of the detailed examinations made of individual flights through a weather echo. He again stressed the fact that examination was by no means complete but indicated a few tentative conclusions reached.

(i) A large bump was usually associated with entry into the sharp vertical edge of a column of weather echo. This was interpreted by the suggestion that a column of echo represents the occurrence within the cloud of a strong upward current.

(ii) The places of maximum turbulence within an echo are associated with the edges of marked columns within the echo and with the troughs between them.

(iii) Even the most turbulent clouds contained quite calm patches which extended at times over 3,000-4,000 yd.

(iv) Echoes with a diffuse or level top frequently give a fairly smooth flight even though marked bumps may occur on entry and departure.

(v) An echo which is showing signs of decay and particularly if it is developing a bright band near the freezing level is generally smooth.

(vi) A column of echo which is still growing is turbulent with a preponderance of up-gusts.

(vii) Large gusts, especially down-gusts, do occur outside the weather echo, but it is probable that the very large gusts, greater than $1g$, occur only in clouds which give echo columns extending to great heights and probably in the edges of those columns or the troughs between them.

Mr. Jones indicated the possibility of the application of his results to the detection of cumulonimbus embedded in frontal layer clouds and concluded with a tribute to the pilots of the Spitfires from the Aero Flight, Farnborough, who had been engaged on this work.

The Director welcomed the visitors from the Ministry of Supply, British European Airways, and other places, and invited them to take part in the general discussion which would follow. He expressed the appreciation of all meteorologists for the R.A.E. pilots who flew into cumulonimbus.

Dr. Hislop (B.E.A.) said that the special flights which B.E.A. were making were to investigate high-level bumps from the point of view of passenger comfort. In their investigation they did not make a special analysis unless the accelerations exceeded $0.2g$. He pointed out that, according to a diagram shown earlier, wind shear in the vertical was large beneath a jet stream and asked if this was not as important as the strong horizontal shear at the sides of the jet. He suggested that waves on the tropopause "breaking" and becoming turbulent, might explain observed bumps there.

Mr. D. E. Morris (R.A.E.), in thanking the Director for the appreciation of the work of R.A.E. pilots, said the hazards of hail had been found greater than those of turbulence in this work. Hail, though infrequent, had seriously damaged the aircraft. He did not think the character of bumps changed from high to low altitudes; clear-air turbulence occurred even below 10,000 ft. He had not noticed any great regularity in the bumps. Regarding "horizontal eddies" he did not think they would be important as a cause of bumps; observations of indicated air speed at low altitude had shown that the turbulent variations were of the same order of magnitude as the vertical turbulent velocities, deduced from accelerometer recordings, and these variations in the horizontal wind were quite incapable of causing the bumps observed. R.A.E. pilots had not noticed any large fluctuations in air speed in the turbulence experienced at high altitude.

More recent flights from R.A.E. have shown a higher frequency of occurrence of turbulence in the stratosphere than the early flights but again no significant maximum at the tropopause. Though they had recently been seeking conditions in the upper air associated with well marked fronts, they had not found such conditions particularly bumpy. He asked if there was any evidence that the turbulence noted persisted, or did it soon die away.

Dr. Goldie thought that perhaps our observations were incapable of detecting large wind shear in the vertical. When there is shear in the horizontal there must also be shear in the vertical. He said that when the product of density and wind speed is plotted against height, a very sharp decrease is found just above the tropopause, on the average, indicating unusually large shear there and this may explain the turbulence often noted at the tropopause.

Dr. Frith also said that high-level bumps were no different from those at low levels and compared the former to those experienced on a windy day flying at 2,000 ft. He suggested that though bumps are often found in a shallow layer, this layer may be found to vary quite rapidly within a much deeper layer. He drew attention to three sizes of turbulent eddies noticeable in an aircraft; first those some 100 ft. across which give bumps, then those some 2-3 miles in diameter and finally those about 20-30 miles in size, the latter two showing up

in the fluctuations of temperature and humidity. He had observed bumpiness to persist for two hours though the bumpy patch appeared to move slightly relative to the air. Mr. Goody of Cambridge had suggested to him that the bumpiness associated with the tropopause might be linked with the radiational heating of the stratosphere spreading downwards and gradually lowering the tropopause surface. He thought that horizontal eddies could not be ruled out as an explanation of some of the bumpiness experienced. He asked if hail was encountered in cloud giving an echo at a height well above the freezing level.

Dr. Stagg pointed out that the extreme conditions found in connexion with marked jet streams made them suitable for meteorological research. Outstanding characteristics, *e.g.* clear-air bumpiness, could be studied in the exaggerated conditions of a jet and general results applied to less extreme cases.

Mr. Sawyer suggested that a study of air movements by means of smoke trails would be of help in determining the nature of eddies which cause bumps. He found great difficulty in understanding how a temperature inversion was not broken down rapidly if vertical eddy velocities were occurring in it and for that reason preferred the idea of horizontal eddy velocities in such circumstances.

Mr. Rowe (B.E.A.) pointed out that bumpy layers were not always shallow. B.E.A. observations indicated that clear-air bumps were of a different nature from those usually found near the ground. Their pilot had described them as giving the sensation of driving a car across a ploughed field. He commented that periodic bumpiness was more serious for aircraft design than irregular shocks.

Mr. Cumming emphasised the magnification of bumps by increased speed of the aircraft, and suggested that meteorologists might soon be asked to forecast bumpy conditions even at high altitude. He also asked if free-air turbulence could cause high-speed aircraft to stall but Mr. Morris replied that this was unlikely.

Mr. Mathewman reminded the meeting of Parr's principle in oceanography, that great stability in the vertical was conducive of turbulence in the horizontal, and suggested that the turbulence in the clear air occurred mainly along isentropic surfaces.

Mr. N. E. Davies, suggested investigating turbulence with a fast and a slow aircraft simultaneously to determine whether the eddy velocities were in the vertical or the horizontal.

Mr. F. E. Coles asked what relation there was between the top of the radar echo and actual cloud top and what was the greatest echo height observed at East Hill, mentioning American reports of echo tops at 65,000 ft. Mr. Coles also drew attention to American reports of a zone of maximum turbulence at the freezing level, and asked if there was any height to be recommended to pilots for flying through a thunderstorm.

Mr. E. Gold thought that probably the effects on an aircraft of horizontal and vertical gusts were indistinguishable and inquired if any relation has been found between high-altitude gusts and the topography beneath.

The Director said that one of the most interesting points was "From where does the supply of energy come to maintain these bumps?" Regarding Mr. Sawyer's query, he understood that the Ministry of Supply proposed to investigate the nature of clear air eddies by means of smoke trails.

Mr. Bannon, in reply, said that there was a large shear of wind in the vertical below a jet stream as well as shear in the horizontal on its sides and suggested this was an additional reason for expecting turbulence near such jets.

Regarding the character of these high-level bumps, he had tried to emphasise the contrast between them and the type of bumps found near the ground on a warm afternoon—dynamic or frictional turbulence as opposed to convectional turbulence. Several R.A.F. pilots had confirmed the impressions of the B.E.A. investigators that this dynamic turbulence gave bumps of some regularity. The persistence of bumpy conditions has been observed for 12–24 hr., in fact, for as long as the particular weather type continued. Whether the turbulence is continuous or takes place as frequent sporadic outbreaks is not known. Regarding the sharp fall off in wind velocity with height above the tropopause, the measurements showing this (radar or radio winds) are of the same type as those used in the analysis of bumpy occasions, so that the same order of magnitude of shear should be detectable in the latter cases, if present.

In reply to Dr. Frith, he found it difficult to understand how heating from above, as suggested by Mr. Goody, could cause turbulence, as this process should be one of stabilization. Regarding Mr. Gold's query, there were insufficient observations as yet, to say whether mountains or other surface effects could be connected with high-level bumpiness. The B.E.A. research flight had found turbulence over Turin, on one occasion, when a N. wind was blowing over the Alps, but wind strength at mountain-top level was only 15–20 kt. as far as could be judged. B.E.A. had also found turbulence over the Scottish Highlands on another occasion.

In reply to Mr. Coles, the highest observed bumpiness (42,000 ft.) occurred above a tropopause at 36,000 ft., about the average height over this country. There is no evidence that bumpiness in the stratosphere is associated with a low tropopause though there are indications that bumpiness in the tropopause region often occurs with a double tropopause.

Mr. Jones, in answer to Dr. Frith, said that hail was reported surprisingly infrequently by the pilots, the most frequent reports of type of precipitation in the echo being rain, even at considerable heights above the freezing level. In reply to Mr. Coles, the greatest echo height observed at East Hill was over 40,000 ft. and there was no doubt that thunderstorm echoes could extend right up to the tropopause. As regards the height to fly through a cumulonimbus, the evidence so far did not warrant recommending any height to a pilot, and the point was strongly emphasised that the successful navigation of a cumulonimbus cloud depended very much on the confidence of the pilot and his handling of the aircraft.

NEWS IN BRIEF

The wedding took place on December 18, 1948, at the Presbyterian Church, Edgware Road, London, of Mr Vander Elst, Director of the Meteorological Service of the Belgian Congo and Miss Patricia Jordan, lately of the International Meteorological Organization Secretariat, Lausanne.

Mr. Vander Elst is well known to many British meteorologists, apart from his present work and international activities, since he served as a Flight Lieutenant in the Meteorological Section, R.A.F.V.R., during the war.

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting of the Royal Meteorological Society was held on January 26, 1949, with the President, Dr. G. M. B. Dobson, F.R.S., in the Chair.

The Symons Medal was presented to the eminent Swedish meteorologist Prof. Tor Bergeron, of the University of Uppsala, the first Darton Prize to Mr. F. H. Ludlam for his paper on ice clouds*, and the second Darton Prize to Mr. C. A. Wood for his paper on the meteorology of Borneo†. Sir Robert Watson-Watt, F.R.S., was elected President of the Society for the coming year.

Dr. Dobson delivered his Presidential address on "Ice in the atmosphere". The address was a comprehensive review of the present state of knowledge of the process of condensation of water vapour at temperatures below freezing point as gained by laboratory experiments followed by an indication of the problems concerned with the application of that knowledge to the atmosphere. Prof. Dobson remarked that our laboratory information was large and concordant but our knowledge on its atmospheric applications was very limited.

After giving some facts on the ratio of and difference between the saturation vapour pressures over plane surfaces of ice and water, Dr. Dobson pointed out that surface tension made an appreciable difference to the vapour pressure over small water drops, and asked what difference there was between the vapour pressure over a large piece of ice and over a small crystal. This question he could not answer, but referred to the recent Guthrie lecture by Sir G. P. Thomson to the Physical Society in which it was shown that the growth of a crystal was an extremely complicated affair with molecules moving about in a concentrated semi-liquid semi-vapour layer till they dropped into their proper niche in the structure.

Dr. Dobson then gave a survey of the historical development of the subject and summed up present knowledge on condensation below freezing point:—

Condensation
temperature °A.

- | | |
|---------|---|
| 273–263 | All nuclei produce water droplets. |
| 263–241 | A very few nuclei (the so-called "Findeisen" sublimation nuclei) produce ice crystals at 263°A. and the proportion of nuclei effective in producing ice crystals steadily increases as temperature falls. The crystals form at supersaturation over water. In this range many more water droplets are formed than ice crystals. |
| 241–232 | At 241°A. large numbers of nuclei become able to form ice crystals and at 232°A. all form ice suddenly, still at supersaturation over a water surface. Below 210°A. all nuclei become less active in forming ice. |

The nuclei which form ice crystals at temperatures above 241°A. appeared to be present only at low levels over land. They were absent over the central oceans, at great heights in the atmosphere, and on high mountains.

*LUDLAM, F. H.; The form of ice clouds. *Quart. J. R. met. Soc., London*, **74**, 1948, p. 39.

†WOOD, C. A.; Report on the weather of the Borneo-Celebes region. *Quart. J. R. met. Soc., London*, **74**, 1948, p. 144.

Other important facts referred to were, that though natural nuclei, except ice crystals themselves, always required supersaturation over a water surface to give condensation, either solid or liquid, ice formed on cadmium-iodide particles at ice saturation, and that no supercooled water droplet has been seen to freeze spontaneously in the laboratory.

Turning to the atmosphere, the lecturer pointed out that Findeisen had found ice particles in cumulus clouds at 259°A . and in stratus at 267°A . while Frith had encountered a pure ice cloud at 253°A . It certainly seemed that ice could form in the atmosphere at a higher temperature than in the laboratory unless we were to suppose that supercooled water droplets in the atmosphere could freeze.

On the question of artificial nucleation of clouds Prof. Dobson thought that it was not very likely to be of importance for rain making, but that it might be possible to transform the droplets of winter anticyclonic stratus into ice particles which would settle out. This would give a bright sunny day instead of a dull one and save electricity and gas.

METEOROLOGICAL OFFICE PUBLICATIONS

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 1. Aviation meteorology of South America

A new series of publications is being made by the Meteorological Office under the general title of Meteorological Reports. The series is designed to make available to the public or special users information which otherwise would exist only in manuscript, or in undigested statistics, but there will be included in this series, a number of papers of this type which would in the past have found a place in Meteorological Office Professional Notes.

The first of these reports deals with the aviation meteorology of South America. Prior to and during the war a number of reports on the meteorology of various countries and air routes were compiled and issued in manifolded form for limited distribution. They were designed to give information on climate and weather in a form which would serve as a book of reference to the aviator and the meteorologist, and the report on South America is no exception. It deals primarily with the air route from Montevideo to Santiago but discusses as a background the general climate of South America and the characteristics of the air masses to which the continent is subject. As appendices general climatological summaries are given for places on the air route as well as tables of the frequencies of visibility and of the height of cloud base.

LETTER TO THE EDITOR

Jet streams

It appears to me that the jet-stream concept is valuable in providing an explanation for the abnormal movements of depressions towards south-south-east which occur in severe winters such as that of 1947. It was a brave fore-caster in those days who predicted that the first of a series of depressions would change its course, as owing to the smoothing of upper air charts there was no rational explanation. The jet stream does, however, stress a known fact, that the isotherms crowd together aloft near a front giving strong winds, and the idea of a narrow but intensely strong air stream quickly transforming the

whole pressure field is less crude than that of a depression being diverted by a wall of cold air with which I used to justify my intuition. With upper air data so sparse, isentropic charts, thickness patterns, etc., do on occasions yield real information, but often sympathetic treatment of the data gives these techniques credit actually inherent in the surface chart, the fact being revealed only when the prebaratic breaks down. Given more observations, existing upper air techniques might be as effective as the jet-stream concept, in which I doubt if there is anything new except terminology.

J. W. THOMPSON

Chivenor, February 2, 1949.

NOTES AND NEWS

Navigation through the ages

At the exhibition "Navigation through the Ages" held at the Royal Geographical Society there were a number of meteorological exhibits shown by the Meteorological Office and by British Overseas Airways Corporation.

The Meteorological Office exhibit consisted of a model of an ocean weather ship with photographs showing the purpose of the weather-ship scheme and the work carried out on board and, to show the seaman's voluntary contribution to meteorological knowledge, two logbooks, the first kept in 1857 by Captain Toynbee (a former Marine Superintendent of the Office) and the second a recent one kept on a British "selected" ship. The importance of meteorology to the air navigator was directly illustrated by a specimen flight forecast compiled for a transoceanic flight and exhibited by British Overseas Airways Corporation.

OBITUARY

Mr. Samuel F. Hurnard, who died on January 13, made a noteworthy contribution to British meteorology by maintaining an unbroken record of rainfall at Lexden, near Colchester, over a period of 60 years. Some time ago he wrote: "The observations have been an interesting pastime, the value and enjoyment of which deepen with the passing of decades of years. There are always surprises in store for the rainfall recorder."

WEATHER OF FEBRUARY 1949

An anticyclone which was centred over Scotland on the 1st crossed the North Sea on the 2nd, and was nearly stationary over central Europe until the 8th. Next morning a vigorous depression moved north-eastwards across England. Later in the day a wedge of high pressure began to extend north-eastwards from an anticyclone near the Azores, and by the 15th this had developed into a large anticyclone centred over southern and central Europe. After the 20th a ridge of high pressure lay over the Azores, France and central Europe for several days, and from the 24th to the 28th there was a well developed anticyclone westward of France. As a result of all these anticyclones the tracks of depressions, except on the 9th, lay far to the north-west of the British Isles.

Mean pressure for the month was above 1030 mb. over most of France, and above 1020 mb. over an area which included central and southern Europe, the Mediterranean, the Azores, Bermuda and the western half of the U.S.A. It was above the average from south-west Russia across to the central part of

North America, with an excess of 13 mb. in central and north-west France, and from 10 to 15 mb. below the average from Iceland across to Spitsbergen and Bear Island.

The weather in the British Isles was distinguished by a large excess of sunshine, particularly in England and Wales. It was mild generally, and dry in England and Wales and east Scotland, but wet in the west and north of Scotland.

During the opening days an anticyclone, centred over Scotland on the 1st, moved south-east to Germany. This system maintained mainly fair, sunny weather apart from local fog until the 6th, when some rain fell in western districts.

A change to unsettled conditions occurred on the 7th when a trough associated with a depression west of Ireland moved across England giving general rain. On the 8th a depression near the Azores approached south-west Ireland and on the 9th it moved rapidly north-east across England to Denmark. Rain fell generally on the 8th and showers, wintry locally, on the 9th, while widespread gales prevailed in England and Wales on the 9th. On the 11th and 12th shallow troughs moving east over the country caused rain in most areas. Meanwhile the Azores anticyclone spread north-east and from the 13th to 17th pressure was high in a belt from west of Spain to south-east Europe and mild fair weather prevailed in England. At the same time pressure was low in the far north and troughs of low pressure moving east caused rain in the north; for example, on the 15th, 2.57 in. fell at Ardgour and 2.38 in. at Fort William. From the 18th to 21st troughs of low pressure, associated with deep Atlantic depressions moving north-east, caused some rain, while gales were registered at a few exposed stations in Scotland and north-west Ireland. On the 22nd a vigorous depression approached north-west Scotland from the Atlantic and moved rapidly away east-north-east; widespread gales occurred in Scotland and Ireland and heavy rain in the Lake District, in Teesdale and the Southern Uplands of Scotland (3.20 in. at Borrowdale, 2.46 in. at Thirlmere, 2.46 in. at Hawes Water and 2.23 in. at Middleton-in-Teesdale).

Subsequently high pressure was re-established from the Azores across France to Austria, while pressure continued low to the north of the British Isles. Mild, mainly fair weather occurred over England except in the north-west but unsettled conditions continued further north. On the 28th a deepening depression south-west of Iceland moving south-east to Denmark caused widespread gales.

The duration of bright sunshine in England was very remarkable; at numerous stations scattered over the country it was the sunniest February on record.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	59	12	+2.6	60	—5	159	42
Scotland	59	13	+2.4	112	0	119	29
Northern Ireland..	55	24	+2.5	102	0	129	30

RAINFALL OF FEBRUARY 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	·93	56	<i>Glam.</i>	Cardiff, Penylan ..	2·37	81
<i>Kent</i>	Folkestone, Cherry Gdn.	1·07	53	<i>Pemb.</i>	St. Ann's Head ..	1·87	67
"	Edenbridge, Falconhurst	1·36	62	<i>Card.</i>	Aberystwyth ..	1·40	56
<i>Sussex</i>	Compton, Compton Ho.	1·79	68	<i>Radnor</i>	Tyrmynydd ..	2·92	56
"	Worthing, Beach Ho.Pk.	1·00	51	<i>Mont.</i>	Lake Vyrnwy ..	3·87	87
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	·96	46	<i>Mer.</i>	Blaenau Festiniog ..	5·79	71
"	Bournemouth ..	1·28	54	<i>Carn.</i>	Llandudno ..	1·26	65
"	Sherborne St. John ..	1·35	62	<i>Angl.</i>	Llanerchymedd ..	1·49	59
<i>Herts.</i>	Royston, Therfield Rec.	1·28	83	<i>I. Man.</i>	Douglas, Borough Cem.	1·81	57
<i>Bucks.</i>	Slough, Upton ..	1·03	61	<i>Wigtown</i>	Port William, Monreith	2·03	66
<i>Oxford</i>	Oxford, Radcliffe ..	1·01	62	<i>Dumf.</i>	Dumfries, Crichton R.I.	3·37	103
<i>N'hant.</i>	Wellingboro', Swanspool	·90	56	"	Eskdalemuir Obsy. ..	6·49	131
<i>Essex</i>	Shoeburyness ..	·48	39	<i>Roxb.</i>	Kelso, Floors ..	·64	38
<i>Suffolk</i>	Campsea Ashe, High Ho.	1·09	79	<i>Peebles</i>	Stobo Castle ..	3·61	131
"	Lowestoft Sec. School ..	·95	68	<i>Berwick</i>	Marchmont House ..	·92	44
"	Bury St. Ed., Westley H.	·91	61	<i>E. Loth.</i>	North Berwick Res. ..	·54	35
<i>Norfolk</i>	Sandringham Ho. Gdns.	·97	59	<i>Mid'n.</i>	Edinburgh, Blackf'd. H.	1·67	101
<i>Wilts.</i>	Bishops Cannings ..	1·41	67	<i>Lanark</i>	Hamilton W. W., T'nhill	5·23	180
<i>Dorset</i>	Creech Grange ..	1·50	52	<i>Ayr</i>	Colmonell, Knockdolian	3·55	92
"	Beaminster, East St. ..	1·80	60	"	Glen Afton, Ayr San ..	6·77	154
<i>Devon</i>	Teignmouth, Den Gdns.	1·49	56	<i>Bute</i>	Rothsay, Ardenraig ..	5·55	139
"	Cullompton ..	1·57	56	<i>Argyll</i>	L. Sunart, Glenborrodale	6·44	107
"	Barnstaple, N. Dev. Ath.	1·26	46	"	Poltalloch ..	5·44	126
"	Okehampton, Uplands	2·58	59	"	Inveraray Castle ..	10·66	157
<i>Cornwall</i>	Bude School House ..	1·03	41	"	Islay, Eallabus ..	3·93	94
"	Penzance, Morrab Gdns.	1·38	41	"	Tiree ..	3·44	100
"	St. Austell, Trevarna ..	2·42	63	<i>Kinross</i>	Loch Leven Sluice ..	2·94	104
"	Silly, Tresco Abbey ..	1·31	47	<i>Fife</i>	Leuchars Airfield ..	1·19	68
<i>Glos.</i>	Cirencester ..	1·56	69	<i>Perth</i>	Loch Dhu ..	9·83	132
<i>Salop.</i>	Church Stretton ..	1·22	52	"	Grieff, Strathearn Hyd.	3·41	97
"	Cheswardine Hall ..	·67	38	"	Pitlochry, Fincastle ..	2·92	99
<i>Staffs.</i>	Leek, Wall Grange P.S.	1·00	42	<i>Angus</i>	Montrose, Sunnyside ..	1·21	66
<i>Worcs.</i>	Malvern, Free Library	·93	52	<i>Aberd.</i>	Balmoral Castle Gdns. ..	1·40	54
<i>Warwick</i>	Birmingham, Edgbaston	·77	46	"	Dyce, Craibstone ..	1·10	48
<i>Leics.</i>	Thornton Reservoir ..	·78	47	"	Fyvie Castle ..	1·56	70
<i>Lincs.</i>	Boston, Skirbeck ..	·72	49	<i>Moray</i>	Gordon Castle ..	1·18	61
"	Skegness, Marine Gdns.	·59	39	<i>Nairn</i>	Nairn, Achareidh ..	1·26	78
<i>Notts.</i>	Mansfield, Carr Bank ..	·87	45	<i>Inv's</i>	Loch Ness, Foyers ..	5·55	171
<i>Ches.</i>	Bidston Observatory ..	1·10	65	"	Glenquoich ..	17·35	168
<i>Lancs.</i>	Manchester, Whit. Park	1·68	87	"	Fort William, Teviot ..	14·11	188
"	Stonyhurst College ..	3·26	97	"	Skye, Duntuiln ..	5·70	124
"	Blackpool ..	1·38	62	<i>R. & C.</i>	Ullapool ..	4·97	120
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·05	61	"	Applecross Gardens ..	6·79	135
"	Hull, Pearson Park ..	·54	32	"	Achnashellach ..	12·19	177
"	Felixkirk, Mt. St. John	·61	36	"	Stornoway Airfield ..	5·56	131
"	York Museum ..	·62	41	<i>Suth.</i>	Lairg ..	4·68	151
"	Scarborough ..	·59	35	"	Loch More, Achfary ..	9·06	137
"	Middlesbrough ..	·44	34	<i>Caith.</i>	Wick Airfield ..	2·09	92
"	Baldersdale, Hury Res.	3·56	118	<i>Shetland</i>	Lerwick Observatory ..	3·53	112
<i>Nor'l.d.</i>	Newcastle, Leazes Pk. ..	·52	34	<i>Ferm.</i>	Crom Castle ..	3·59	122
"	Bellingham, High Green	2·30	91	<i>Armagh</i>	Armagh Observatory ..	2·51	113
"	Lilburn Tower Gdns. ..	·74	37	<i>Down</i>	Seaforde ..	1·45	48
<i>Cumb.</i>	Geltsdale ..	2·47	95	<i>Antrim</i>	Aldergrove Airfield ..	1·74	72
"	Keswick, High Hill ..	5·12	104	"	Ballymena, Harryville ..	3·04	94
"	Ravenglass, The Grove	2·39	78	<i>L'derry</i>	Garvagh, Moneydig ..	3·02	96
<i>Mon.</i>	Abergavenny Larchfield	1·77	55	"	Londonderry, Creggan	4·17	131
<i>Glam.</i>	Ystalyfera, Wern House	3·02	59	<i>Tyrone</i>	Omagh, Edenfel ..	4·09	137

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, OCTOBER 1948

STATIONS	PRESSURE			TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE		
	Mean of day M.S.L.	Diff. from normal	Diff. from normal	Mean values			Wet bulb	Total	Diff. from normal			Days	Daily mean	Per- centage of possible			
				Max.	Min.	Max. and Min.									°F.	°F.	°F.
London, Kew Observatory	mb.	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.	in.	hr.	%	
1017.9	+3.5	+3.5	+3.5	68	27	57.2	43.3	50.3	47.8	87	7.8	1.83	-0.87	10	2.9	27	
Gibraltar ..	1017.5	+0.3	+0.3	83	53	74.3	62.8	68.5	64.6	84	5.3	3.20	—	8	7.3	65	
Malta ..	1017.8	+1.8	+1.8	80	58	78.1	65.7	71.9	70.0	80	6.1	5.96	—	6	7.1	63	
St. Helena ..	1017.7	-0.1	-0.1	67	52	61.8	53.6	57.7	54.1	98	9.7	3.42	+1.71	20	—	—	
Lungi, Sierra Leone	1012.7	—	—	89	69	85.8	72.5	79.1	74.8	89	7.7	8.89	—	21	—	—	
Lagos, Nigeria	1012.5	+1.5	+1.5	92	68	87.8	70.3	79.1	76.6	83	8.8	2.18	—	15	6.1	51	
Kaduna, Nigeria ..	1014.6	-0.5	-0.5	95	62	80.6	67.8	78.7	65.9	51	3.0	1.36	+0.30	4	8.3	67	
Chileka, Nyasaland	1011.0	-0.1	-0.1	97	59	88.2	64.1	76.1	62.2	50	4.0	5.42	+4.91	7	8.5	69	
Lusaka, Rhodesia ..	1013.8	-0.3	-0.3	91	52	81.6	59.6	70.6	59.1	54	3.4	1.85	+0.70	6	7.8	62	
Salisbury, Rhodesia	—	—	—	86	48	69.5	54.2	61.9	53.4	63	5.0	1.60	-0.05	10	—	—	
Cape Town ..	1014.8	-0.2	-0.2	88	44	76.6	54.5	65.5	53.3	55	3.5	2.58	+0.91	9	8.8	70	
Germiston, South Africa	1009.5	0.0	0.0	94	66	89.7	74.7	82.2	76.1	90	3.4	7.00	+2.10	10	7.4	64	
Mauritius ..	1010.1	+0.3	+0.3	95	75	88.7	77.2	82.9	76.9	86	4.2	2.11	+0.44	6	8.1	69	
Calcutta, Alipore Obsy.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Bombay ..	1009.8	+0.9	+0.9	95	72	89.7	75.8	82.7	76.5	85	6.3	9.21	-1.94	11	7.5	64	
Madras ..	1010.7	+0.7	+0.7	88	70	86.4	74.3	80.3	74.7	88	6.6	8.97	-4.39	22	7.1	59	
Colombo, Ceylon ..	1009.9	+0.2	+0.2	91	72	88.7	74.7	81.7	76.8	80	7.0	2.63	-5.44	11	—	—	
Singapore ..	1014.9	+1.2	+1.2	89	63	81.7	72.5	77.1	71.2	76	—	3.13	-1.81	12	6.9	59	
Hongkong ..	1010.8	-4.0	-4.0	97	47	74.4	54.7	64.5	55.8	49	3.9	0.65	-2.20	9	9.6	75	
Sydney, N.S.W. ..	1010.7	-4.1	-4.1	86	39	65.3	46.7	56.0	50.7	61	7.8	3.58	+0.95	20	4.8	37	
Melbourne ..	1014.8	-1.2	-1.2	91	42	67.7	49.3	58.5	52.6	56	7.0	4.38	+2.64	12	6.8	53	
Adelaide ..	1018.1	+1.3	+1.3	89	45	71.1	53.2	62.1	57.0	61	5.0	1.84	-0.38	13	8.0	63	
Perth, W. Australia	1016.4	+1.5	+1.5	96	35	79.5	51.1	65.3	53.7	45	2.4	0.24	-0.42	2	—	—	
Coalgardie ..	1014.5	-1.7	-1.7	96	53	81.3	60.2	70.7	61.5	59	2.4	0.03	-2.50	2	10.2	80	
Brisbane ..	1004.6	-5.7	-5.7	77	36	58.5	43.6	51.1	46.8	64	8.1	4.11	+1.85	22	5.1	39	
Hobart, Tasmania	1008.4	-4.7	-4.7	67	37	58.6	46.0	52.3	49.5	75	8.1	4.43	+0.35	17	5.5	42	
Wellington, N.Z. ..	1013.3	+0.1	+0.1	85	70	80.6	73.1	76.9	72.6	80	8.2	3.22	-5.07	19	3.6	29	
Suva, Fiji ..	1011.4	+0.4	+0.4	89	71	86.4	73.5	79.9	77.0	79	7.1	15.97	+8.80	22	6.9	56	
Apia, Samoa ..	1011.9	+0.4	+0.4	91	72	88.8	74.0	81.4	76.1	80	4.8	4.34	-3.12	10	8.6	73	
Kingston, Jamaica	—	—	—	89	71	86.8	75.8	81.3	77.7	80	7.8	2.84	-4.92	22	—	—	
Grenada, W. Indies	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Toronto ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Winnipeg ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
St. John, N.B. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Victoria, B.C. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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EXTENDED-RANGE FORECASTING

The Meteorological Office Discussion, held at the Imperial College, London, on February 28, was on the experimental preparation of four-day forecasts at present being carried out in the Forecasting Research Division. The discussion was opened by Dr. A. G. Forsdyke.

Introductory.—Since September 1, 1948, the Forecasting Research Division has prepared a twice-daily series of surface and upper air charts covering a large part of the northern hemisphere. Based on these charts, and on certain other considerations to be referred to in this discussion, experimental four-day forecasts were begun, once weekly, in October 1948. The experience gained since then is considered to have justified an extension of the experiment, and since February 1, 1949 the forecasts have been prepared twice weekly, on Tuesdays and Fridays.

The necessity for charts covering the hemisphere for purposes of extended-range forecasting is generally agreed. The methods used in the experiment are, to a large extent, the same as those in the daily routine forecasting, but the emphasis is on the large-scale features of the hemispherical circulation patterns rather than on individual pressure systems. The essential feature of the work is the prominence given to the 1000–500-mb. thickness chart, and the ideas concerning development and the thermal pattern put forward by Dr. R. C. Sutcliffe^{1,2*}.

Background.—We confine our attention in this discussion to medium-range forecasts covering periods of a few days, and make no attempt to deal with the extensive researches into methods of long-range forecasting covering months or seasons. Much of the research in medium-range forecasting so far carried out in this and other countries has been purely empirical. We shall not deal with those this evening, but, from the various medium-range forecasting projects, we select the following three as being best representative of the background to the present experiment :—

- (a) the work of F. Baur in Germany from 1932 up to the second World War ;
- (b) the work of C. E. P. Brooks in this country, 1942–44 ; and
- (c) the work of the U.S. Weather Bureau Extended Forecast Section.

* These numbers refer to the list of references on p. 131.

Under Baur, ten-day forecasts for Germany were issued by the Research Institute for Long-Range Weather Trends, German State Meteorological Service, beginning in 1932. Baur's work was based largely on correlations with past weather, but its main interest for us lies in the fact that the statistical forecasts were modified by considerations of the "broad-weather situation". This is rather loosely defined, but may, following Sir Gilbert Walker, be regarded as "a condition of the atmosphere which controls the weather for several days, remaining sensibly constant in spite of changes in the weather from day to day". In Baur's work the pressure distribution at 5 Km. was most commonly taken as characterising the "broad-weather situation", and this became associated with the idea of steering of surface pressure systems by the upper currents. Its importance for medium-range forecasting lay in that a persistent upper pressure distribution might steer a series of surface systems on approximately the same track at intervals over a period of days, thus determining the general character of the weather for the area affected.

The principal work of Brooks consisted in forecasting the mean pressure distribution over Europe and the North Atlantic for six- or twelve-day periods by the method of pressure trends. The trends were essentially estimated from pressure anomalies at a large number of stations, and though there was some appeal to physical reasoning the method was mainly empirical.

The work of the U.S. Weather Bureau Extended Forecasting Section is described in more detail below.

American extended-range forecasting methods.—These are described in a number of reports the most recent of which is by J. Namias³. They are based on considerations relating to the general atmospheric circulation, which is assumed to conform to the usual model; at the surface, polar and tropical easterlies separated by the westerlies of middle latitudes; aloft (at a sufficiently high level), general westerlies.

The strengths of those components of the circulation are indicated by circulation indices. Typical of these is the zonal westerly index, derived from the mean south-north difference of pressure between the parallels of 35° and 55°N. , but expressed in metres per second by the geostrophic relation. "Normal" values of this index for the whole northern hemisphere range from about 2.2 m./sec. in winter to 0.8 m./sec. in summer. Obviously, deep Icelandic and Aleutian lows with well developed subtropical highs give rise to high values of the index; if these systems are displaced from their normal positions or broken up so that there is a strong meridional interchange of air, the index is low. But the converse does not necessarily hold. In any case the methods of forecasting future values of the indices are entirely empirical, and they appear to be used for checking the prognostic charts rather than for their intrinsic value. The emphasis is on five-day means rather than daily values of the indices.

The closed circulations of the surface pressure pattern usually give place aloft to a series of ridges and troughs, lying very roughly from south to north, with amplitudes up to 20° of latitude or more. These systems are basic in American practice. The level of 700 mb. is selected as standard. The 700-mb. prontours are first prepared and the prebaratics derived from them, in the first instance "mechanically" using forecast thicknesses, but the prontours themselves may have to be adjusted subsequently in the light of the existing and forecast sea-level pattern. Again the main emphasis is on five-day mean ridges

and troughs, which appear to move at only about one fifth of the speed of individual systems appearing on the daily charts. Being slow moving the mean troughs are held to determine the general character of the weather over the extended period (they indicate the regions in which the individual troughs will be at their deepest).

Numerous "rules", mostly empirical, are used for forecasting the positions of mean troughs and ridges. Among those having some physical basis are rules based on the movement of long waves (the ridge and trough system) and constant-vorticity trajectories.

Rossby⁴ has shown that, under certain simplifying assumptions, the velocity of a sinusoidal wave in the zonal current is given by

$$c = U - \frac{\beta L^2}{4\pi^2},$$

where c = wave velocity

U = zonal velocity

L = wave-length between adjacent troughs or ridges

β = rate of change northward of the Coriolis parameter.

For steady state conditions, $c = 0$, stationary wave-lengths L_s we have

$$L_s = 2\pi\sqrt{(U/\beta)}.$$

The stationary wave-length increases with the zonal velocity. It follows that, for a given U , if the wave-length differs from L_s some movement of the troughs and ridges may be inferred. In practice, it is found that these formulæ require considerable empirical modification.

Under the assumption of zero divergence the vertical component of total vorticity of a moving parcel of air remains constant. Owing to the variation of Coriolis parameter with latitude, the constant-vorticity trajectory is a series of waves similar to those under discussion. In practice, the 700-mb. troughs and ridges are compared with those derived on the assumption of constant vorticity; the differences enable convergence and divergence and hence changes in the troughs and ridges to be inferred.

Other cartographical aids are used, among them moisture-distribution charts and climatological charts, too numerous to be mentioned.

In the final stage of the work daily prognostic charts are prepared for the forecast period. It is essential, of course, that these shall average out to agree with the forecast five-day mean charts.

Forecasting Research Division Experiment.—As in the U.S.A., current surface and upper air charts of the northern hemisphere are used, but, with the limited resources available, no attempt has been made to prepare an elaborate system of auxiliary charts: our medium-range forecasting section is much smaller than its American counterpart. The main difference between the American methods and ours is largely one of emphasis and lies in the significance we attach to the thickness pattern. The essential coupling of different levels, in development, through the thickness pattern, has been stressed by Sutcliffe¹. We regard the flow patterns at all levels as being brought into mutual relationship through the thickness pattern. The latter may indeed be partly dependent on the flow pattern insofar as it is affected by changes of temperature due to ascent and subsidence, but it depends also upon certain external influences—advection, temperature of underlying surface and radiation; so the thickness

pattern constitutes a parameter for the hemispherical circulation, having a form to some extent independent of that circulation. The American school on the other hand treat the flow patterns at different levels as basic dynamical features and do not give quite the same prominence to their inter-dependence.

Contrary also to American practice, we have not so far used mean four-day charts either retrospectively or prognostically.

Sutcliffe² has discussed the relation of cyclonic and anticyclonic development to the thickness pattern and has also described other uses of thickness charts in general forecasting. To these may be added the advantage for medium-range forecasting which they have to some extent in common with Baur's broad-weather situation and the mean troughs and ridges basic in American practice, namely, that they depict a slowly moving, slowly changing pattern, through which the short-lived features move. As the tempo of changes in the surface chart limits normal forecasting to some 24-48 hr., so that of thickness changes affords some justification for attempting forecasts for the extended period.

The following circumpolar charts are prepared twice daily* on the scale 1 : 30,000,000 :—

- (i) analysed surface chart ;
- (ii) 1000-mb. contours and 1000-500-mb. thicknesses ;
- (iii) 500-mb. contours ; and
- (iv) 300-mb. contours.

These, with one or two subsidiary diagrams, constitute our cartographical aids for the experimental forecasts.

Forecasts covering the next four days are prepared twice weekly, on Tuesdays and Fridays ; at present they are essentially a research experiment, and are not distributed. Skeleton prebaratics and pre-thickness charts covering the area from the Rockies to the Urals are prepared, usually for each of the first three days of the forecast period. Their purpose is to indicate the expected trend ; forecasts cannot be given to that degree of precision which would be required by strict adherence to the prebaratics.

Experimental technique.—Full weight is, of course, given to the surface charts, which in addition to their obvious uses in applying standard forecasting technique are particularly useful for locating distant pressure systems which are potential factors for our weather over the four-day period. Track charts are prepared and used for extrapolating the paths of pressure systems over the forecast period.

Extrapolation is likewise applied to the thickness charts. Since November 1948 monthly diagrams have been prepared showing in chronological sequence the positions, at 12-hourly intervals, of the main thermal troughs and ridges along the parallel of latitude 55°N. It is evident from these diagrams that the main thermal troughs and ridges persist for at least several days. They tend as a rule to move steadily from west to east through a large range of longitude, their movement being slow compared with that of surface pressure systems ; if the geographical situation and surface circulation are favourable, thermal troughs and ridges may remain quasi-stationary for long periods.

*The 500- and 300-mb. charts are plotted twice daily but drawn up only once daily.

Two typical charts showing the movement of thermal troughs and ridges over the period February 7-15, 1949 are reproduced in Fig. 1. They show for the most part a steady eastward movement of these systems, though in the latter part of the period troughs tend to become stationary over the continents.

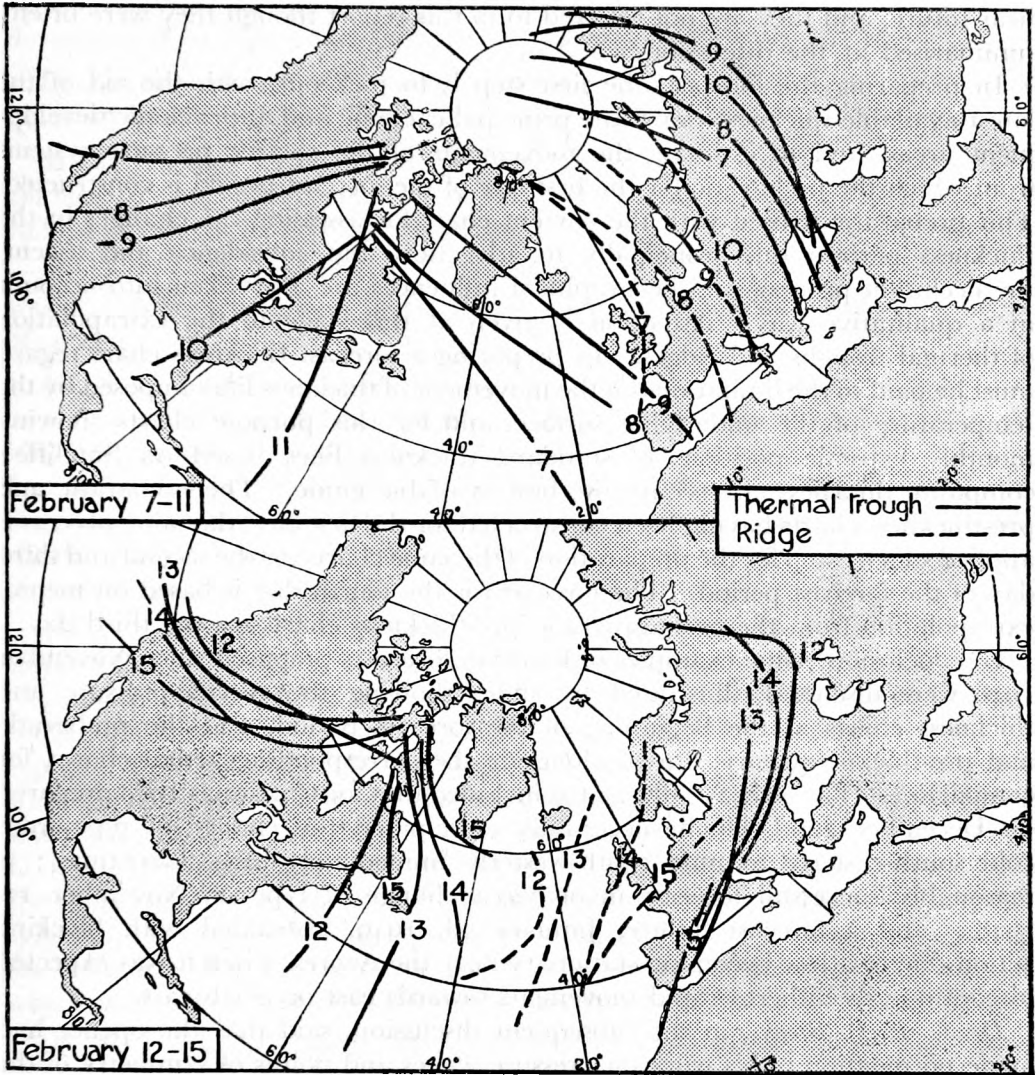


FIG. 1—TWO TYPICAL CHARTS SHOWING THE MOVEMENT OF THERMAL TROUGHS AND RIDGES, FEBRUARY 7-15, 1949

Certain circulation indices have been calculated and plotted daily since early November 1948, so far with little profit. Changes in these indices are obviously and clearly related to simultaneous changes in the general hemispherical circulation, but there is as yet no indication that they have any prognostic value. Considerations of wave-length and constant vorticity (following Rossby), intensity and latitudinal location of the main thermal gradients, and symmetry or otherwise in the hemispherical thickness pattern have a minor place in the experiment, but, so far, our ideas in these fields are vague and uncertain and their possible use must await further research.

The main forecasting tool in the present experiment is the connexion between development and the thickness pattern based on Sutcliffe's theory¹. This is, so far as we can judge, the most important step forward in forecasting for many years. The practical implications of these ideas which are becoming increasingly widely known are being developed in papers which will be available in the near future, and they are not referred to in this report though they were briefly summarised at the discussion.

In preparing the forecast, the first step is to pick out, with the aid of the latest available thickness chart, the principal cyclonic and anticyclonic development areas, and to estimate the movements of the surface pressure systems from which the prebaratic for the first day of the forecast period is constructed. This prebaratic is used with the current chart for assessing the changes in the thickness pattern due principally to advection, but subsidence and ascent, the occlusion process, and geographical influences are also taken into account in a qualitative way. Attention is given at this stage to the extrapolation of thermal troughs and ridges. In preparing a forecast thickness chart regard must be paid to the limitations on the movement of thickness lines imposed by the temperature of the underlying surface, and for this purpose charts showing monthly extreme positions of standard thickness lines based on Sutcliffe's composite thickness charts² are the best available guide. The prebaratic and pre-thickness charts having been constructed for the first day, the same process is applied step by step for the preparation of the same charts for the second and third day of the forecast period. The forecast for the fourth day is based on mental extrapolation from the prebaratic and pre-thickness charts for the third day.

In conclusion, some examples of four-day forecasts prepared since November 1948 were discussed, illustrated by slides showing the surface-pressure and thickness charts at the beginning of the forecast period, and the prebaratic and pre-thickness charts drawn alongside the corresponding actual charts, for comparison. The forecasts illustrated included that for Christmas 1948 prepared on December 22nd which successfully anticipated the change of type from cold south-easterly to mild south-westerly immediately after Christmas; a reasonably successful forecast involving a change of type on November 12, 1948; and a forecast failure, January 28, 1949, associated with blocking action due to a low becoming stationary near the Azores, when it was expected to continue its hitherto rapid movement towards east or north-east.

Dr. C. E. P. Brooks, in the subsequent discussion, said that the opener had made no mention of his work on pressure waves and points of symmetry of the pressure-time graph, carried out at the same time as the trend forecasts. Dr. Forsdyke, in reply, said that, having regard to the time available for discussion, he had selected the trend forecasts as being the more successful and as having the closer connexion with the medium-range forecasting experiment; the work on pressure waves and points of symmetry was purely empirical. With this Dr. Brooks agreed, remarking however that the work on pressure waves was the more interesting.

The Director said that he was gratified to see that the Meteorological Office was using charts and parameter values for individual days instead of concentrating entirely on mean charts. Dr. Sutcliffe's work was in particular a most promising development for forecasting, all the more welcome as indicating that in this country, though not overlooking the great importance of work elsewhere, we were also working on our own ideas.

Inst. Cdr. Thorp said that during the war he was responsible for forecasts for three or more days in connexion with convoy routing. He had visited the U.S. Weather Bureau Extended Forecasting Section and had had the privilege of studying their methods of forecasting. Rossby's wave formulæ were difficult to apply in practice, but the main difficulty lay in the forecasting of blocking action—the general slowing down of the zonal circulation associated with the development of high or low pressure through a larger range of latitude.

Dr. Goldie said that observations obtained with the Bruce gun showed that blocking action extends in some cases to at least 100,000 ft.

Mr. F. A. Sharp spoke on the desirability of the examination of temperature changes at very high levels (up to 100 mb.) in forecasting the persistence or collapse of warm anticyclones and cold depressions.

Mr. J. L. Galloway said that extended forecasting using the method of Baur was still being carried on in Germany, with, however, only a limited degree of success.

Mr. A. H. Gordon remarked that, in the slides shown, the charts stopped short at about latitude 30°N. , and suggested that the medium-range forecasts might well be affected by happenings in low latitudes and the analyses should therefore be carried to the equator. *Dr. Forsdyke*, in reply, said that the slides were for illustrative purposes only and did not include the whole of the working charts; nevertheless the working charts were as a rule incomplete in low latitudes on account of the lack of regular data.

Mr. E. Gold said that the opener had given the impression that the analyses stopped short at the Rocky Mountains as if they constituted a complete boundary to the circulation instead of merely a barrier. An attempt ought to be made to assess scientifically the effect of the mountains on the flow pattern. In reply to *Mr. Gold*, after the meeting, *Dr. Forsdyke* said that the Rockies were certainly not regarded as an absolute boundary; they formed a convenient starting point for estimating the flow pattern, both in this country and in the U.S.A. Empirically, regard was had to the fact that the Rockies usually give rise to a ridge in the upper flow pattern, which in turn gives rise down-stream to ridges and troughs, spaced according to the zonal velocity. There were grounds for believing that the constancy of total vorticity in a vertical air column, which is shortened on crossing the mountains, requires such a flow pattern.

Dr. R. C. Sutcliffe spoke in general terms on medium-range forecasting, stressing the desirability of experiments of the type under discussion to keep investigators alive to the realities of the problem. Unlike short-range forecasting, which was bristling with known problems, medium-range forecasting problems had yet to be formulated as a result of the experience it was hoped to gather from the experiment.

A. G. FORSDYKE

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PARTIAL THICKNESSES AS A GUIDE TO INSTABILITY

BY R. MURRAY, M.A.

The "partial thicknesses"—*i.e.* height intervals 1000–700 mb. and 700–500 mb.—of upper air isobaric charts readily depict stability and instability in the atmosphere. This fact has been known since the time such charts were first constructed, but it is perhaps generally appreciated only rather vaguely. That partial thicknesses must give some indication of stability and instability clearly follows from the correspondence between the height intervals and the mean temperatures of the air columns between isobaric surfaces.

It was considered worth while to examine the surface and upper air observations of May 1948 to see just how close was the above-mentioned relationship. The upper air observations chosen were those over the British Isles, Malta, Gibraltar, Lagens, Meeks Field and Bardufoss.

The "700 thickness" (partial thickness 1000–700 mb.) and the "500 thickness" (partial thickness 700–500 mb.) were correlated with the occurrence or non-occurrence of precipitation of an instability type (showers, thunderstorms, instability rains) within 3 hours of the time of the upper air ascent. All observations associated with frontal rain were omitted. Out of a total of 715 ascents there were 471 associated with the non-occurrence of instability precipitation. The remaining 244 ascents gave instability precipitation occurring within a radius of about 100 miles of the station (in 140 of these precipitation occurred at or within sight of the station concerned). The choice of the time interval ± 3 hr. and of the area of 100-miles radius, together with the representation of instability by the occurrence of instability precipitation is somewhat arbitrary, but seems reasonable.

With abscissæ and ordinates the 700 and 500 thicknesses respectively, Fig. 1, showing the non-occurrence of instability precipitation, and Fig. 2, showing the occurrence of instability precipitation, were then constructed. In Fig. 1 line *aa* was tentatively drawn so that about 95 per cent. of the observations were on or above it. In Fig. 2 line *bb* was drawn so that about 95 per cent. of the observations were on or below it. It is thought that lines *aa* and *bb* would be in only slightly different positions if many more observations were used in the construction of Figs. 1 and 2 than in this sample of 715. Hence it is suggested that the graphs may be used in making a rough yet useful assessment of stability and instability from upper air charts. Above *bb* refers to stability; below *aa* refers to instability. A point falling between *aa* and *bb* indicates uncertainty as regards stability or instability, thus suggesting that a more detailed consideration of the upper air structure, especially the moisture distribution and the exact height and intensity of temperature inversions, is called for.

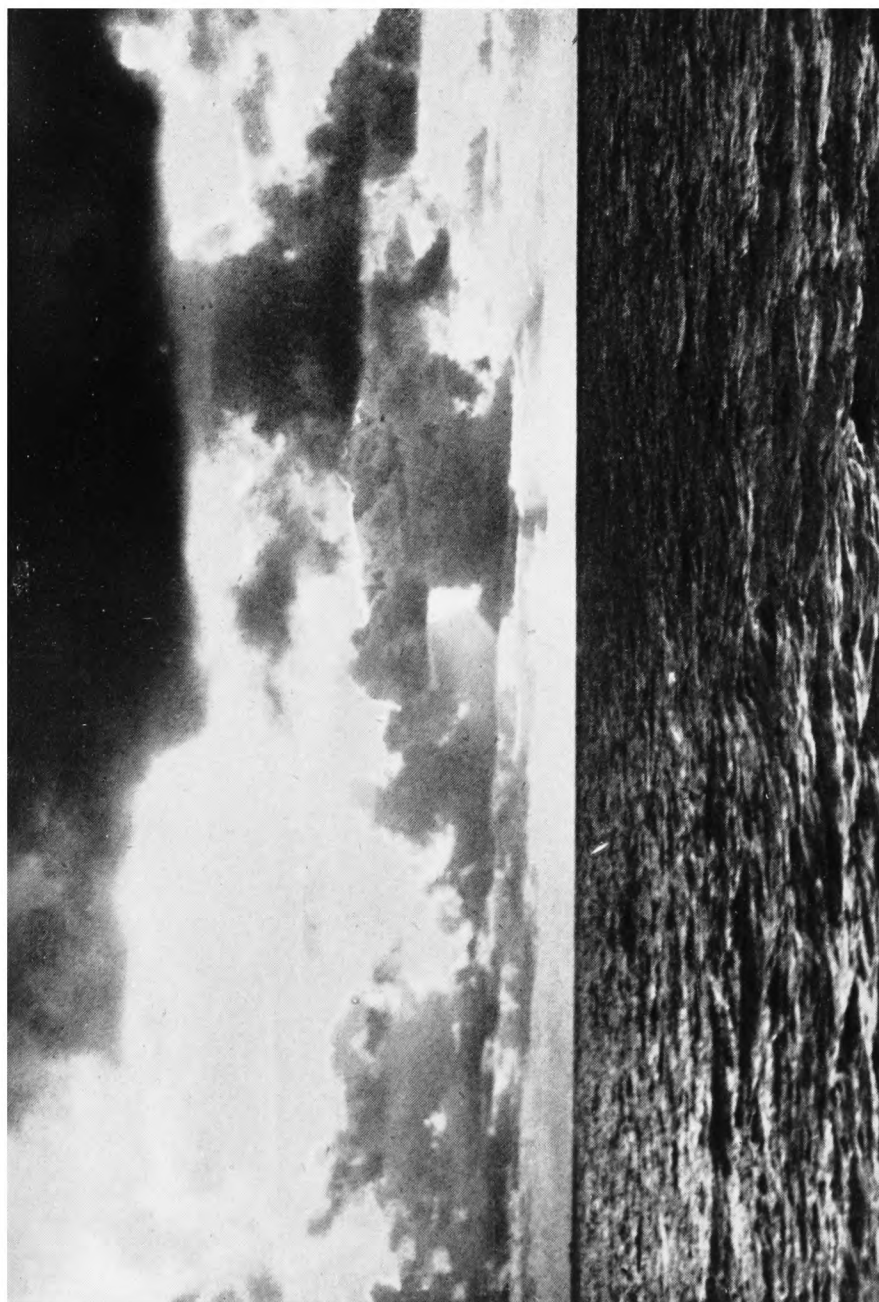
The near-straight line *cc* was constructed from the 700 and 500 thicknesses associated with the moist adiabatics on the tephigram. As a first approximation it might be assumed that *cc* represented a sort of neutral line, and that points above and below *cc* referred to stability and instability respectively; but facts appear to indicate that a much better neutral line must lie between *aa* and *bb*, and thus have less slope than line *cc*. One of the reasons for this is probably that instability phenomena can usually develop in a shallower unstable layer in cold air (where the freezing level is low) than in warm air.



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EVERNING AFTER A DAY OF DRIZZLE ON THE ATLANTIC

During July 15, 1948 a small wave on a feeble front passed through station JIG (53°50'N. 18°40'W.) giving periods of slight drizzle but without giving any marked change in temperature or dew point, and hardly ever a completely overcast sky. This photograph was taken after the weather had begun to improve and shows precipitation falling from banks of nimbostratus with patches of altostratus, altocumulus and cirrus above.



Reproduced by courtesy of O. M. Ashford

EVENING ON THE ATLANTIC IN POLAR AIR

This photograph, taken towards sunset on July 20, 1948 at station JIG shows the typical sky with large cumulus and good visibility associated with unstable polar air.

It may be argued that, because upper air ascents are already available, to use partial thicknesses in estimating stability and instability is like putting the cart before the horse. But there is more to it than that. The idea is of some practical use in relation to both (1) actual and (2) forecast charts.

(1) The vast amount of general information to be assimilated by the forecaster makes it of some importance to have the broad picture of stability and instability in a handy form—*i.e.* already on the upper air charts through the relation between the 700 and 500 thicknesses given by Figs. 1 (or 2). The forecaster is thus able to see at a glance which regions have ascents requiring more critical analysis—the unnecessary checking of all tephigrams is thereby avoided.

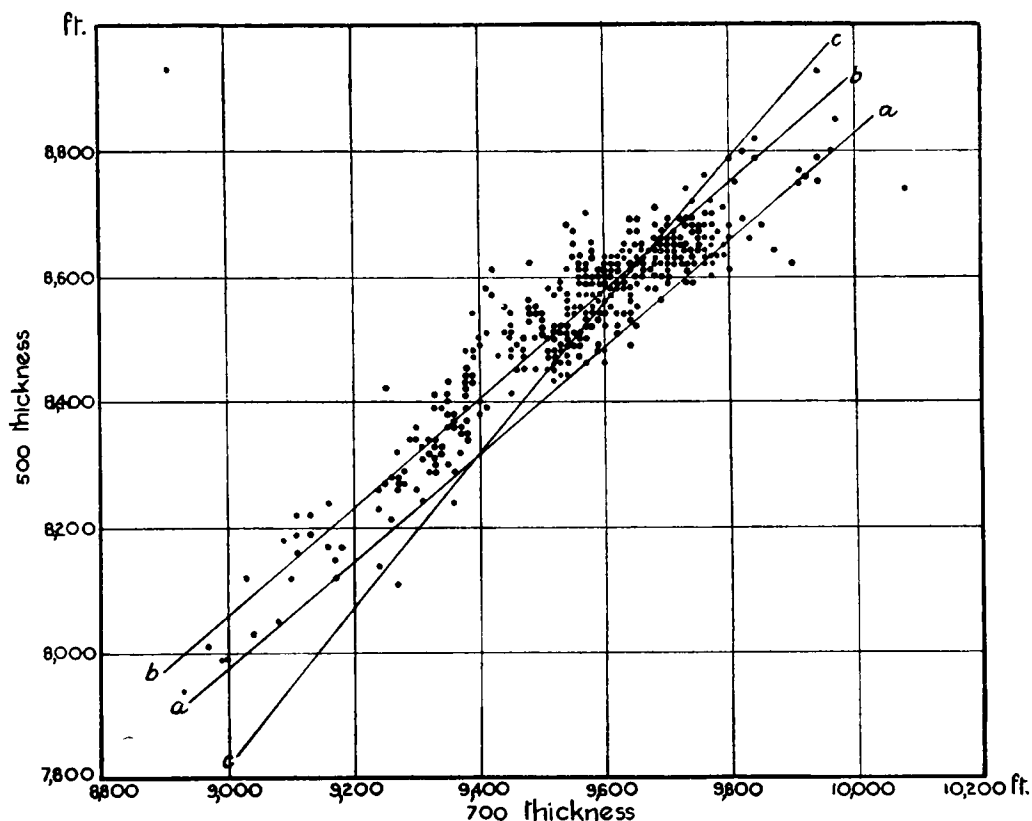


FIG. 1—VALUES OF 700 THICKNESS AND 500 THICKNESS WHEN INSTABILITY PRECIPITATION DID NOT OCCUR

112 additional observations at points already marked, 2 of these falling below line *aa*.

Reversing the argument, regions of marked instability (as indicated by Sferic reports, say) may be known where no upper air ascents are available (*e.g.* the 0900 and 2100 G.M.T. soundings are rather scanty over Europe), so that the forecaster in constructing his upper charts must ensure that the 700 and 500 thicknesses are drawn in such a way as to be consistent with the known occurrence of instability, thus ensuring accuracy in the absolute contours because these are so dependent on the partial thicknesses.

(2) Stability changing to instability, or *vice versa*, can best be anticipated from a consideration of the partial thicknesses on the upper air charts. In this

connexion differential advection, differential heating, the movement of cold or warm pools are of importance.

For instance, using the thickness diagram, it may be found that the 700 and 500 thicknesses intersect between the lines *aa* and *bb*, and a check of the actual ascent shows little instability. Suppose now that the upper air charts indicate that the 500 thickness is increasing relative to the 700 thickness (say, because the 500 thickness is warming due to subsidence and/or advection), then clearly the air is becoming more stable. On the other hand, it may be that a decrease in the value of the 500 thickness is indicated (say, because colder air is being advected at upper levels or because the air at lower levels is becoming

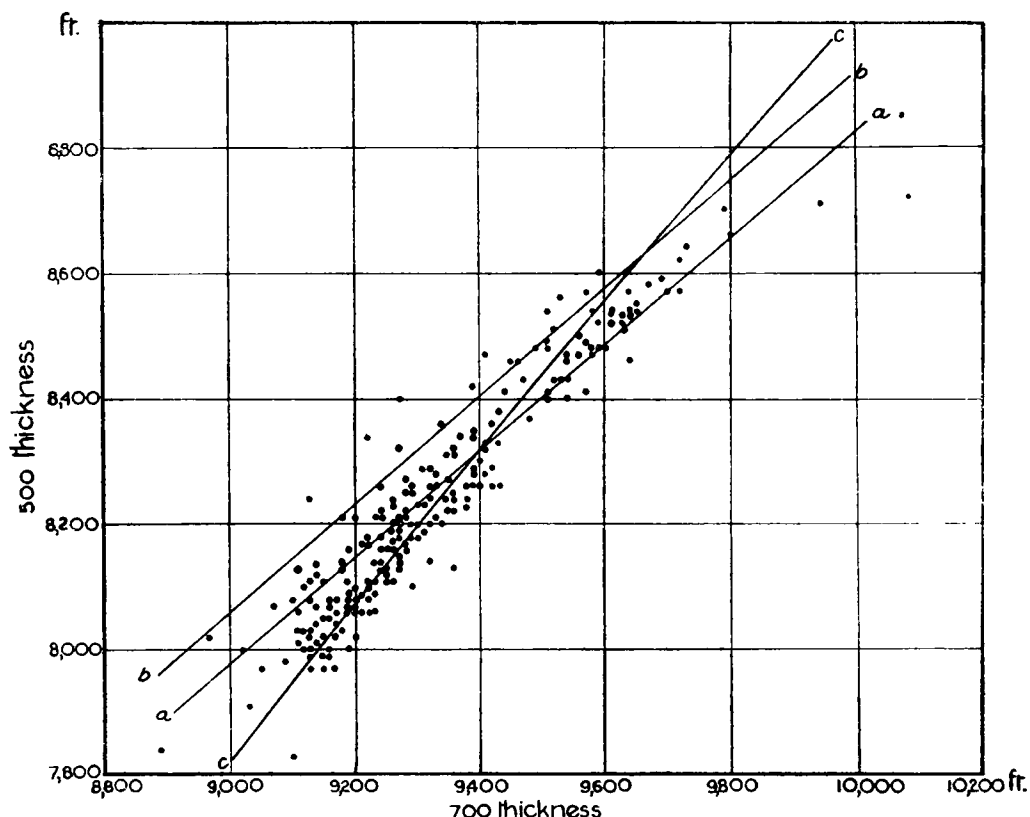


FIG. 2—VALUES OF 700 THICKNESS AND 500 THICKNESS WHEN INSTABILITY PRECIPITATION DID OCCUR

36 additional observations at points already marked, none above the line *bb*.

warmer through advection and/or surface heating), and the air is becoming more unstable; and the probable development of instability precipitation must be considered if the expected change is sufficiently great.

It may be mentioned that the Prontours (the forecast upper air charts issued by the Central Forecast Office) contain inherently the 700 and 500 thicknesses, so enabling an assessment of stability and instability to be made, but no official routine forecast of particular upper air ascents is issued.

One word of warning is necessary. Instability in a comparatively shallow layer below 700 mb. may be sufficient to cause some precipitation (normally of slight intensity); then the value of the 500 thickness is immaterial so that the underlying idea in this note will be invalid.

REPORT ON AN EARTH TREMOR IN EAST ANGLIA ON MAY 28, 1948

BY L. L. ALEXANDER

An earth tremor was experienced at Mildenhall, Suffolk, at 17h. 02m. 30s. G.M.T. on May 28, 1948. It was sufficiently strong to be the cause of conversation amongst the local population and preliminary enquiries showed that it had been felt over a fairly wide area. To investigate the area over which it had been felt, the public were requested through the press to send their experiences of the tremor to the Meteorological Office at Mildenhall. The notice appeared in most of the local papers in East Anglia and in *The Times*, *Daily Herald* and the London evening papers. A total of 232 replies was received by telephone and letter. These observers ranged from the head of a Cambridge college to housewives and schoolboys.

So that an estimate could be made of the scale of shock felt by each observer, the following table was devised:—

- Force 1 Rumbling or slight vibration
- Force 2 Rumbling or moderate vibration
- Force 3 Rumbling or heavy vibration
- Force 4 Rumbling accompanied by slight vibration
- Force 5 Rumbling accompanied by moderate vibration
- Force 6 Rumbling accompanied by heavy vibration
- Force 7 Articles fell from shelves or slight structural damage.

It should be noted that this scale is designed to meet the needs of this particular earthquake which were very small; it is not therefore directly comparable with other existing scales.

This scale has been used to plot the reports in Fig. 1 together with the number of such reports, *e.g.* 3/1 indicates that three reports were received from the place shown on the map, each reporting slight vibration or rumbling. Where slight damage has been caused or articles have fallen from shelves, the report has been surrounded by a ring—there were two reports of goods falling from shelves in shops at Downham Market and one report of a cracked wall. Only two other reports of falling articles were received, from Felixstowe and from near Sudbury.

Only a small percentage of observers gave an estimate of the length of duration of the tremor and these varied considerably. Less than five seconds is generally agreed by most capable observers in the area to be the nearest estimate of the duration.

The question as to whether the rumbling preceded the vibration or *vice versa* or whether they were completely coincidental was also investigated but no satisfactory figures were obtained. Eight per cent. of observers wrote on this question—4·5 per cent. gave the rumbling preceding the vibration and 3·5 per cent. the vibration first—with no general agreement in any particular district.

The area in which the shock was felt was bounded by Peterborough—Kings Lynn—Lowestoft—Felixstowe—Bradwell Bay—Kettering. The rough centre of this area is Thetford. The area of greatest violence was in and near Downham Market.

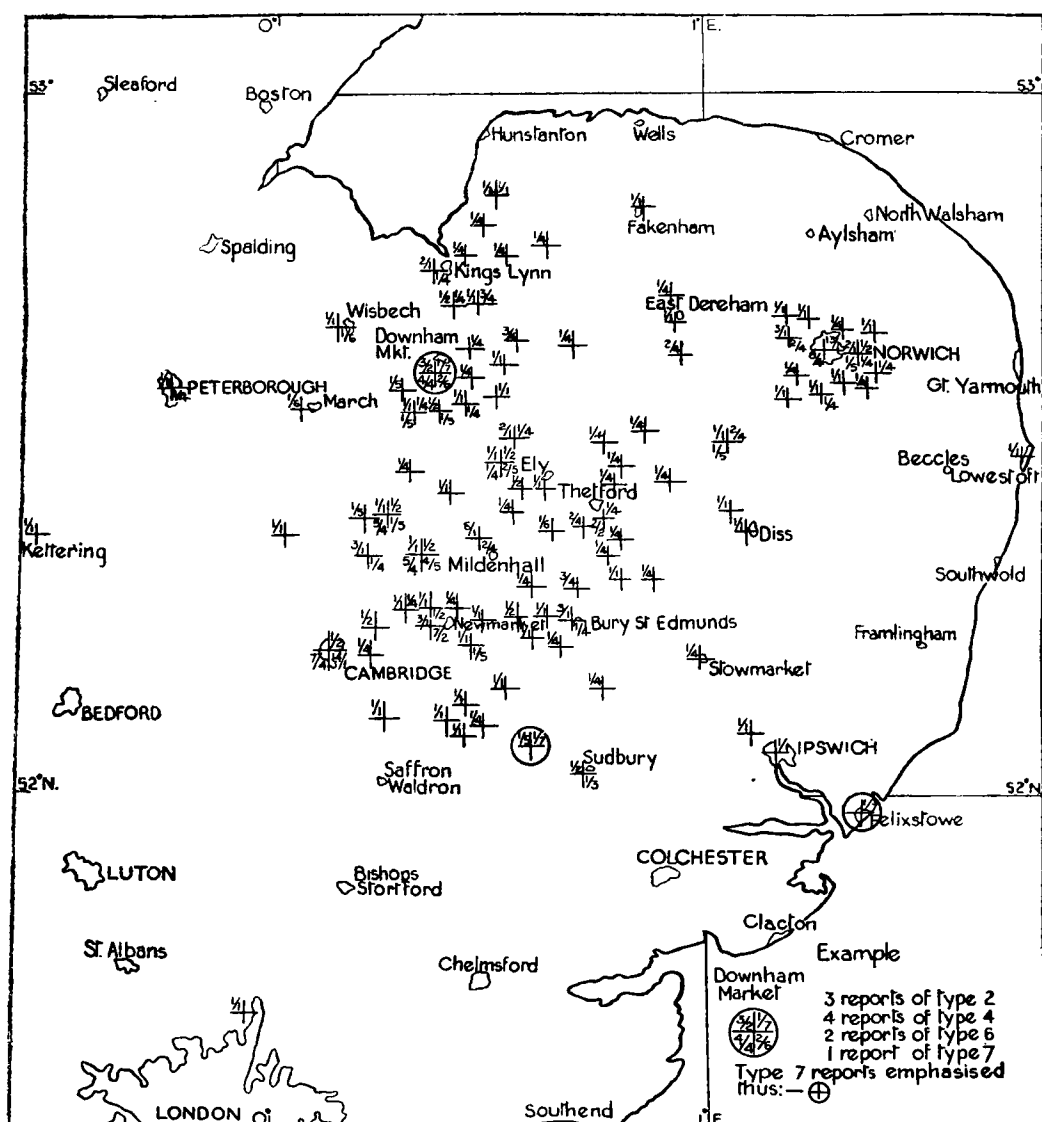


FIG 1—ANALYSIS OF REPORTS OF EARTH TREMOR ON MAY 28, 1948

ANALYSIS OF REPORTS

	Rumbling or vibration only	Both rumbling and vibration
Cambridge	19	10
Ely	14	18
Downham Market	6	12
Kings Lynn	12	16
Norwich	24	17
Thetford	6	21
Bury St. Edmunds	13	14
Newmarket	8	7
Ipswich	2	0
Outlying areas	9	4

Mostly the rumbling was described as "like thunder", although several reports state that a loud crack like an explosion preceded the rumbling. This "explosion" was not peculiar to any district. The vibration was mainly likened to the passage of a heavy vehicle or to the vibration caused by a bomb exploding in the vicinity. Both were of sufficient intensity to cause alarm to women and children in a number of places.

The barograms at Mildenhall each show a small downward movement of the pen at approximately 1700 G.M.T.; the shock was not registered by any other barograph in the vicinity.

The Kew seismographs, both short-period and Galitzan, clearly showed the compression wave of this disturbance at 17h. 02m. 53s. and the distortion wave at 17h. 03m. 07s. G.M.T.; the disturbance was therefore located about 120 Km. from Kew. No record has been received of any other recording of the tremor by seismic instruments.

Extracts from typical letters received are shown as an indication of classification.

Example 1—Classified as Force 1

From Miss P.M., Cambridge.

. . . I am a patient at the above Nursing Home and on Friday last, I felt a distinct vibration as I lay in bed. . . .

Example 2—Classified as Force 2

From Mrs. P. V. H., Downham Market.

. . . We live on the upper storey of an old building and at the time I was sitting with my child in our sitting room listening to the news on the B.B.C. Suddenly our cosy stove started to rattle and then my chair and the whole room shook and swayed as I counted up to 5 or 6 (I have previously been in an earthquake in India and I recognised it to be an earth tremor). For some little time afterwards various ink bottles and ornaments rattled on my desk. For how long I can only guess as by this time I was attending to my child who was very scared. . . .

Example 3—Classified as Force 4

From Mr. F. A. S., Soham.

. . . I was on duty in the signal box at Soham station when there was quite a rumbling noise like thunder also the windows rattled violently. . . . Talking on the subject to the Train Control Office at Cambridge some half hour later, I was told that quite a number of signalmen had reported the happening. . . .

Example 4—Classified as Force 5

From Mrs. M. McG., Cambridge.

. . . when I heard what I thought was a heavy bomb falling at a great distance. The tremor was so disturbing that I felt physically sick, a similar reaction to that experienced by me during the London blitz. . . .

Example 5—Classified as Force 1

From Mr. A. F., Kings Lynn.

During the Dog Watches on 28th May, the writer being indoors at the

time experienced a long distant roar (duration approx. 10–15 seconds) time not noticed. No physical vibration felt or noticed.

Example 6—Classified as Force 7

From Mr. E. R., Downham Market.

. . . when I heard a rumbling noise and it knocked some things off my shop shelf. . . .

Mr. H. V. Shaw of West Bromwich has kindly supplied the following extracts on past seismic activity in East Anglia; they are taken from “A History of British Earthquakes” by Charles Davison.

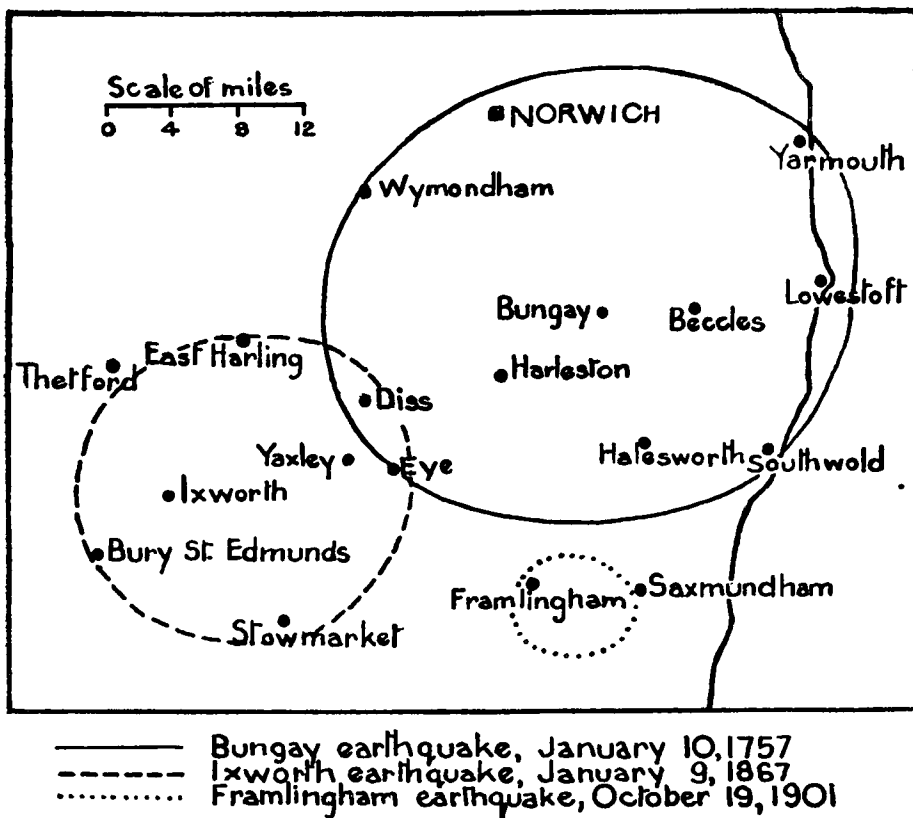


FIG. 2—ISOSEISMAL LINES OF THE BUNGAY, IXWORTH AND FRAMLINGHAM EARTHQUAKES OF 1757, 1869 AND 1901

1757, *January 10*. Centre of disturbed area in $52^{\circ}29'N$. $1^{\circ}26'E$.

The boundary of the disturbed area is represented approximately by the continuous black line in Fig. 2. It is 32 miles long, 27 miles wide, and contains about 680 square miles. Its centre lies 1 mile north of Bungay, and the longer axis is directed a few degrees north of east.

1869, *January 9*—Intensity 4*—Centre of disturbed area in $52^{\circ}18.1'N$. $0^{\circ}57.4'E$, 14 records from 11 places.

The disturbed area, the boundary of which is represented by the broken line in Fig. 2, is 20 miles long from east to west, 18 miles wide, and contains

*These intensity numbers refer to a modification of the Rossi-Forel Intensity Scale, Intensity 4 indicating “windows, doors, fire irons, etc. made to rattle.”

about 280 square miles. Its centre is at the village of Walsham-le-Willows or 9 miles south of East Harling.

The shock consisted of a quiver, accompanied by a rumbling sound like thunder or the rapid passing of a heavy carriage. At Yaxley and West Harling, pheasants crowed and flew from the ground in alarm.

1901, *October* 19.—About 7.25 p.m.—Intensity 4*—Centre of isoseismal 4 in $52^{\circ}12'6''\text{N}$. $1^{\circ}15'0''\text{E}$., 18 records from 11 places and 27 negative records from 23 places.

The isoseismal 4 is represented by the broken line in Fig. 2. It is nearly circular, $6\frac{1}{2}$ miles long from east to west, 6 miles wide, and contains 31 square miles. Both shock and sound were observed at Rendlesham ($2\frac{1}{2}$ miles south of the isoseismal) and the sound was also heard, but no shock felt, at Dennington (1 mile north-west) and Earl Soham (3 miles west).

The centre of the isoseismal lies 1 mile south-west of Sweffling and 15 miles north-east of Ipswich. There was a sudden shock followed by a brief tremulous movement lasting a few seconds. The sound, usually of brief duration, was heard by all the observers.

1901, *October* 22.—About 9.15 a.m.—Intensity 4—Centre of isoseismal 4 in $52^{\circ}12'7''\text{N}$. $1^{\circ}15'2''\text{E}$., 22 records from 13 places and 27 negative records from 23 places.

The isoseismal 4 coincides very nearly with that of the preceding earthquake. The shock and sound were observed at Earl Soham, the shock was also felt at Snape (1 mile south-east of the isoseismal) and the sound was heard at Cretingham ($3\frac{1}{2}$ miles west). The shock was similar to that of the first earthquake, consisting of one prominent vibration followed by tremulous motion and lasting altogether about 3 sec. In 15 out of 17 records, the sound was compared to types of short duration.

METEOROLOGICAL RESEARCH COMMITTEE

The fifth meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on March 3, 1949.

Two papers, "The relation between the standard deviation of temperature at constant pressure and at constant height" by A. F. Crossley and "Report on some synoptic studies of atmospheric dynamics" by J. S. Sawyer, were considered.

Papers on dynamic instability, ageostrophic motion ahead of warm fronts and the relation between wind and the pressure field in the tropics, were also discussed.

OFFICIAL PUBLICATIONS

The following publications have recently been issued.

BRITISH RAINFALL 1946

This publication, the eighty-sixth in the series and the first to appear since 1939, retains the essential features of pre-war issues, although paper shortage has necessitated some curtailment and re-arrangement. The volume is a comprehensive summary of the rainfall of 1946, both as regards its incidence during

the year and its variation from place to place. The records of about 5,000 observers are discussed with the aid of numerous maps and tables.

The book is arranged in two parts :—

Part I consists of eleven chapters under the headings : The work of the British Rainfall Organization, The distribution of rainfall in time, Droughts and dry spells, Rain spells and wet spells, Duration of rainfall, Heavy falls in short periods, Heavy falls on rainfall days, Monthly rainfall, Seasonal rainfall, Total rainfall in 1946, Evaporation and percolation.

Part II is the General Table of Rainfall and gives the recorded total fall with the numbers of rain days and wet days at about 5,000 stations in Great Britain and Northern Ireland, together with the names of the observers or other authorities.

Two volumes, still to be published, will contain data for the war years : the first, for 1940, 1941 and 1942, and the second for 1943, 1944 and 1945.

METEOROLOGICAL REPORTS

No. 2—Aviation meteorology of the Azores

Standing as they do midway between Europe and America the Azores have attained a new importance with the coming of regular transatlantic flight. Their rugged peaks, moreover, are breeders of cloud and weather with a meteorological interest that has unique features. To the forecaster in western Europe who uses the Azores observations as one of his main supports in synoptic analysis the correct interpretation of those observations is vital.

On all these counts the publication of a full report on the meteorology of the Azores is very welcome, particularly when it has been compiled by officers who have had considerable experience of the difficulties of forecasting the vagaries of the weather of these islands.

ROYAL METEOROLOGICAL SOCIETY

Large-scale vertical motion in the atmosphere was discussed at a meeting of the Society held at 49, Cromwell Road, South Kensington, on February 16, Sir Robert Watson-Watt, President, in the Chair.

The discussion was opened by Mr. J. K. Bannon who first remarked briefly on the importance of vertical motion in atmospheric dynamics and the difficulties in measuring or deducing it. He then went on to describe a method of estimating up-currents from the rate of rainfall*. In an ascending cloud mass in which conditions do not vary greatly in the horizontal and when the up-currents are not large enough to support small raindrops, the cloud particles do not contain much water (or ice) and hence the rate of release of precipitation from the ascending cloud is, to a good degree of accuracy, the rate at which the saturated water-vapour content of the air decreases as the temperature falls due to adiabatic expansion. Thus when the temperature structure of the air is known and also the base and top of the ascending current of air, rate of rainfall measurements on the ground (allowing for any evaporation of the rain as it falls)

*BANNON, J. K. ; The estimation of large-scale vertical currents from the rate of rainfall. *Quart. J. R. met. Soc., London*, **74**, 1948, p. 57.

may be used to calculate the mean up-current in the cloud mass. Results obtained from rainfall records in the Hebrides show that up-currents of 10 to 20 cm./sec. are usual in typical North-Atlantic depressions.

Mr. J. S. Sawyer then described two methods of deducing vertical movement in the atmosphere. The first method, due to Graham*, depends on being able to trace the horizontal movement of the air so that the position of a particular parcel of air at the time of one upper air temperature observation is known at the time of the previous temperature soundings; any difference at a fixed level between the observed temperatures of approximately the same parcel of air is assumed to be due to vertical motion with adiabatic changes and hence the vertical velocity is inferred. The second method depends on the approximate relation between rate of change of vorticity and the divergence of the horizontal wind field (the vorticity equation) and the relation between this horizontal divergence and the vertical motion (the equation of continuity). Using the geostrophic wind as an approximation to the true wind it is thus possible to deduce the field of vertical motion from pressure charts. In spite of the many approximations, results by this method are self-consistent and agree with observed phenomena (up-currents in rain areas, down-currents in anticyclonic areas); they also agree qualitatively with results obtained by Graham's method.

Professor P. A. Sheppard gave an interesting account of some work being carried out under him at Imperial College, by Mr. H. A. G. Van Ufford and others. The eight wind-finding stations in the British Isles are the apexes of seven triangles with sides of length about 200–300 miles. The horizontal divergence over each of these triangles was evaluated from the winds observed at the corners (specially supplied by the Meteorological Office to the nearest degree in direction and nearest knot in speed), at 100-mb. intervals between the levels 900 mb. and 200 mb. (*i.e.* approximately from 3,000 to 40,000 ft.) for all possible occasions in the period December 1947 to February 1948, inclusive. These measures lead immediately to the vertical velocities at these levels by the equation of continuity.

Analysis of the results was not complete but Professor Sheppard demonstrated some preliminary conclusions. Curves were shown giving the distribution with height of the mean up- and down-currents for the triangle Larkhill-Liverpool-Downham Market for January 1948; when there was general ascent below 500 mb. the maximum velocity (between 7 and 8 cm./sec.) occurred at about 16,000 ft.; with general descent in the troposphere the maximum (between 6 and 7 cm./sec.) occurred at about 20,000 ft. In both cases the mean vertical velocity at the tropopause (up and down respectively) was about 4 cm./sec. Up and down velocities of up to 30–40 cm./sec. were deduced in particular cases even in the lower stratosphere.

Mr. M. K. Miles compared vertical velocities he had worked out for one occasion by three different methods. The velocities deduced by a direct method (from observed winds) and by Bannion's method were comparable, but that by Graham's method was much smaller, probably because the latter was an average over 6 hours.

Dr. R. C. Sutcliffe welcomed the attack on the vertical-motion problem, one of the central problems of meteorology, and was particularly enthusiastic

*GRAHAM, R. C.; The estimation of vertical motion in the atmosphere. *Quart. J. R. met. Soc., London*, **73**, 1947, p. 407.

about Professor Sheppard's work. He advocated the fullest use of the British-Isles network of upper air observing stations (the best in the world) to discover the basic facts about typical weather situations ; models, so determined, could then be applied to similar weather types in other parts of the world.

Professor Sheppard, in answering a question from Mr. C. S. Durst, said that since winds measured by radar methods were means over a depth of about 3,000 ft., the small variations in wind, which L. F. Richardson thought would make numerical analysis impossible in some cases, were smoothed out. He had never obtained a ridiculous or inconsistent result by his method.

Mr. O. M. Ashford pointed out, as noteworthy, that the vertical velocities as deduced by Professor Sheppard showed no discontinuity at the tropopause.

Sir Robert Watson-Watt, in concluding, emphasised the importance of quantitative results in meteorology as in other sciences, and said that he thought the results demonstrated during the discussion showed exciting progress.

MICROMETEOROLOGY IN AMERICA

On February 24, Professor O. G. Sutton gave a talk to members of the staff of the Meteorological Office regarding his visit to the U.S.A. in the Autumn of 1948. The following is a brief account of this talk.

Professor Sutton began by saying that, up to 1939, the United Kingdom was in a better position regarding knowledge of micrometeorology than anywhere else in the world, thanks chiefly to the excellent basis established by Sir Nelson Johnson when he was in charge of the Meteorology Section at the Experimental Station, Porton. This was not an idle claim, but one that had been amply substantiated by war-time conferences with meteorologists from other countries and by the post-war examination of captured German documents. Since the cessation of hostilities there had been a growing interest in this aspect of meteorology, and it was particularly heartening to know that the United States, with its vast scientific potential and acknowledged leadership in technology, was now taking a much deeper interest in the subject than heretofore.

The speaker then explained that he had been granted leave of absence from his academic duties by the War Office to accept an invitation from the U.S. Weather Bureau to deliver a course of lectures on atmospheric turbulence at Washington, and to advise on certain problems which are now being investigated at various centres in America. Originally, it had been intended that some lectures should also be given at the University of Chicago, the Massachusetts Institute of Technology and New York University, but, owing to difficulties caused by the dock strike, it was possible only to fulfil the engagement at New York.

The field covered by the lectures was briefly as follows : first, a general account of turbulence from the aerodynamical aspect, followed by a résumé of facts concerning the meteorology of the lower atmosphere. The lectures then dealt briefly with the familiar " classical " theories and the reasons for their failure, and went on to describe attempts to produce a workable theory by making k vary with height according to empirical laws. The modern era starts with the introduction of mixing-length theories and thence to the statistical approach, regarded by many as the most promising yet evolved. A considerable amount of time was devoted to discussing the problems of diffusion and evaporation, and the course concluded with an account of turbulence

in a variable density gradient and the problems associated with convection. The lectures were well attended by a keen and critical audience, whose enthusiasm made the task of the lecturer thoroughly enjoyable.

Professor Sutton then went on to discuss points of interest from various projects now in active development. He mentioned investigations into upper air turbulence being made by a team working under Dr. Harry Wexler, with the object of extending our knowledge of long-time-scale diffusion, on lines initiated in England by Richardson and Proctor. He described the activities of the Meteorology Group at Brookhaven, Long Island, and dwelt at some length on the elaborate and finely executed instrumentation employed, including two 420-ft. towers, one of which carries wind, temperature and humidity elements at frequent intervals so that a very detailed picture of the profiles can be obtained at any time. This work is directed by Dr. Norman Beers, and has as its primary aim the study of micrometeorology in relation to the dispersion of effluent from stacks.

Considerable interest was aroused by the lecturer's description of the means adopted for investigating in detail the temperature field near the ground at Camp Detreck, Maryland, again in connexion with the dispersion of smoke. The temperature-measuring elements in this case are very small thermocouples, which are used unscreened and without artificial aspiration, a preliminary investigation having shewn that the customary precautions are unnecessary with such small elements. This work, which is in charge of Major Suggs, is still in its early stages but shews excellent promise of producing results of the greatest interest. The lecturer was greatly impressed by the excellent quality of the recording obtained, the combination of quick-response instruments and photographic records giving a very vivid picture of the fluctuations of air temperature near the ground.

During Professor Sutton's stay in the States public attention was drawn to the problems of atmospheric pollution by a disaster at the small industrial town of Donora, near Pittsburgh, Pa. The speaker was invited to discuss the matter with the Industrial Hygiene Foundation of Pittsburgh, and he explained the difficulties involved in attempting to reconstruct what actually happened in the valley during the "smoggy"* days with inadequate meteorological data, the nearest weather station being at Pittsburgh Airport, about 20 miles away. Other problems discussed while in America included one relating to the design of a power station in the vicinity of a busy commercial airfield, where the chimneys cannot be made very high. Finally, the speaker drew attention to a purely statistical method of dealing with the "smog" forecasting problem. This has been developed for the Los Angeles area and consists essentially in watching the movements of the 700-mb. surface in relation to wind anomalies.

In conclusion, Professor Sutton said that his stay in the States had been most enjoyable and inspiring, and that he felt sure that in a very few years, American enterprise and skill would mean significant advances in micrometeorology.

The discussion which followed was animated and keen interest was shewn in many aspects of the work, particularly that relating to the measurement of temperature.

*"Smog" is a U.S. abbreviation for "smoke fog."

ROYAL SOCIETY OF ARTS

Two lectures were recently delivered at the Royal Society of Arts on subjects of interest to meteorologists.

The first was given by Lt. P. G. Satow, D.S.C., R.N., on January 4 and was entitled "The application of radar to the science and art of maritime navigation". Lt. Satow very ably sketched the history of the marine radar and how its war-time use primarily for the detection of enemy craft was readily adapted for navigational purposes. Like so many war-time inventions its use in peace time has turned out to be very great and, if intelligently used, it can be an enormous asset to the navigator. Lt. Satow very clearly described the principle of the instrument and illustrated the types at present in use in merchant ships. He pointed out the limitations of the instrument and emphasised that, even if a ship was fitted with radar, the navigating officer still had the same need of sea sense and seamanship as of old.

In discussing the limitations of the instrument Lt. Satow led up to the meteorological conditions affecting radar. He pointed out the enormous ranges which are obtained as the result of freak propagation and the sudden reductions in range which can occur as a result of thunderstorms, frontal situations, heavy rain and the like. He very ably illustrated these meteorological conceptions with the use of slides giving typical cloud formations followed by weather maps and photographs of radar displays in which the interference due to weather was very clearly shown.

Finally, Lt. Satow demonstrated the use to which radar could be put from a hydrographic point of view, illustrating with the use of charts the remarkable detail of topographical features that a radar scan can pick up.

The second lecture was given on January 11 by Captain J. W. Josselyn, D.S.C., R.N. (retd.), lately Director of the Naval Meteorological Service. Captain Josselyn's lecture was entitled "Weather forecasting at sea" and was designed to illustrate the type of information that the forecaster at sea was likely to be asked for and the limitations in the material at his disposal. Captain Josselyn discussed not only the naval point of view, but also that of the merchant seaman and stressed that, in brief, wind, state of sea and visibility were the three items with which the seaman was chiefly interested. He pointed out that with the collective broadcasts that were issued nowadays the seaman or professional forecaster aboard a ship could prepare his own charts, and, with the addition of information from his own and other ships in the vicinity, build up quite a comprehensive picture of the weather situation and issue quite a reasonable forecast.

For the benefit of those present who were not meteorologists, Captain Josselyn briefly sketched the life history and theory of temperate zone depressions and the principle of air masses. He illustrated cases where the seaman could, by using surface data alone, make quite reasonable forecasts of impending weather, but emphasised, at the same time, the value of upper air data when this is available. He went on to discuss the formation and movement of tropical storms and methods of forecasting these, and illustrated some unusual tracks of these storms.

After discussing the forecasting of visibility at sea, Captain Josselyn wound

up by illustrating the relative simplicity of the forecaster's work at sea compared with that of his colleague ashore who, admittedly, had more material at his disposal, but who had to serve many more varied interests.

G. E. N. FRANKCOM

LETTERS TO THE EDITOR

Barograms from big ships

Mr. Bibby's comment on my letter appearing in your issue for February 1949 calls for some further information from me.

Conditions on board the 15,000-ton whale-factory ship *Balaena* near the edge of the southern ice were ideal for studying the effects of gusty winds and heavy seas separately. Heavy seas broadened the barograph trace even when the wind at the ship was light, but fine traces were obtained with gusty winds of up to force 6 and over so long as the sea was calm (owing to shelter given by ice).

There was no such opportunity to distinguish and isolate the various factors contributing to the motion of the pen arm when high seas were running. By far the main factor, to all appearances, was the purely mechanical acceleration associated with the motion of the ship, and other contributions such as pressure oscillations accompanying the swell seemed to be of much less account.

My impression is that the oscillations of the pen arm of the barograph were always in phase with the motion of the ship. The instrument was set fore and aft in the vessel, and with heavy swells coming beam-on the rolling of the ship carried the pen regularly back and forth between the chart on the drum and the glass of the case. The trace was always broad at these times and of similar breadth to that produced by the swinging of the pen arm in heavy seas accompanied by pitching of the vessel without much rolling.

H. H. LAMB

March 1, 1949.

The statistician in meteorology

I have read Dr. Sutcliffe's exhilarating article on forecasting research in the *Meteorological Magazine* for March 1949. I am sorry to note his desire to squeeze out the statistician.

I feel this comes from a misconception of the role of the statistician in scientific research. Statistics is the science of handling large numbers of observations. Where there are so many observations that it is difficult to comprehend their significance then statistical analysis seeks to express the properties of the mass of data in a simple and easily understood form. If the research worker has a theory which he wants to test experimentally, statistical analysis will tell him if his data supports his theory strongly or weakly and give precise limits to the accuracy of any parameters he may be estimating. It is true that statisticians estimate correlation coefficients and regression equations but it is far more important for them to say whether the relationships derived are significant and to give the degree of confidence to be placed in the estimates.

Statistical analysis is not a method to be used when the mathematician or theoretical physicist has failed to evolve a theory, but a powerful tool whereby the research worker can put his theory under test and see just how well experimental evidence supports the theory.

G. A. TUNNELL

March 30, 1949.

NOTES AND NEWS

"Lee thermal" depressions over south-east Scotland, July 14-15, 1948

On both July 14 and 15, 1948 the only parts of the British Isles affected by thunderstorms were in south-east Scotland where "lee thermal" depressions developed in a northerly air stream which had crossed the mountains. Lee depressions or troughs of low pressure are not uncommon in that area, but only occasionally are conditions also favourable for thunderstorms, and still more rarely are thunderstorms confined to that area on two consecutive days.

A depression centred west of Iceland on July 10, 1948 had moved slowly to the North Sea by the 13th with little change of pressure at the centre. By midday of July 14 a trough of low pressure had formed across south Scotland in the northerly air stream which covered the whole of the country. Stratiform cloud persisted all day on the 14th in north Scotland and over most of England and Wales, with temperatures remaining below 60°F. and less than two hours' sunshine at most places. In the Central Lowlands of Scotland, however, the stratus broke up during the morning. There were 8.5 hr. sunshine at Leuchars, Fife, and 8.6 hr. at Renfrew (near Glasgow). Temperature reached 68°F. at both places, compared with only 57°F. at Lossiemouth and Rattray in the same air mass to the north and at Tynemouth to the south. A thunderstorm occurred at Donibristle, Fife, during the evening.

The trough of low pressure over south-east Scotland on the morning of July 15 intensified by surface heating and developed into a well marked "lee thermal" depression by midday. It attained its maximum intensity by mid afternoon, continued as a centre of low pressure until the evening and died out again at night. At Leuchars a surface wind veer from E. by S. force 3 at 1200 to SW. by S. force 3 at 1300 G.M.T. indicates that there was enough gradient wind at that time to overcome the sea breeze. The wind remained between SW. and S. from 1300 to 1500, veered to W. by N. force 2 at 1600 and then settled down to a light E. or NE. drift. Charts at three-hourly intervals over the period 0600-2100 G.M.T. are given in Fig. 1.

Temperature readings of 70°F. at Leuchars and Renfrew on July 15 were the highest reported throughout the British Isles—more than ten degrees higher than in the north and the extreme south of Scotland. Dalwhinnie, 1,176 ft. above mean sea level in the Grampians, with a temperature of 65°F., was four degrees warmer than London. Renfrew recorded 11.0 hr. of bright sunshine, Leuchars 8.6 hr., Montrose 7.7 hr., Dalwhinnie 7.2 hr. and Prestwick 7.1 hr. In contrast Lossiemouth to the north and most places in the Midlands and south-east England were completely sunless.

The radio-sonde ascents at Leuchars at 0800 and 1400 G.M.T. on July 15 are given in Fig. 2, wet-bulb temperature being plotted against the dry-bulb value at the same pressure level. From these ascents the air over Leuchars was too dry for thunderstorms. Presumable there was more moisture further inland in the region of convergence at the centre of the low. At Leuchars cumulonimbus clouds were first seen at 1330 to the north and north-west, with tops rising to 20,000 ft. Thunder was heard at 1505 G.M.T. A thunderstorm moved from west to east across the Leuchars area at about 1600 G.M.T. and then appeared to the observer to turn northwards over the sea. No cumulonimbus cloud was observed to the east before the arrival of the storm. There was another thunderstorm at Leuchars at 1835 while showers continued until 2045 G.M.T.

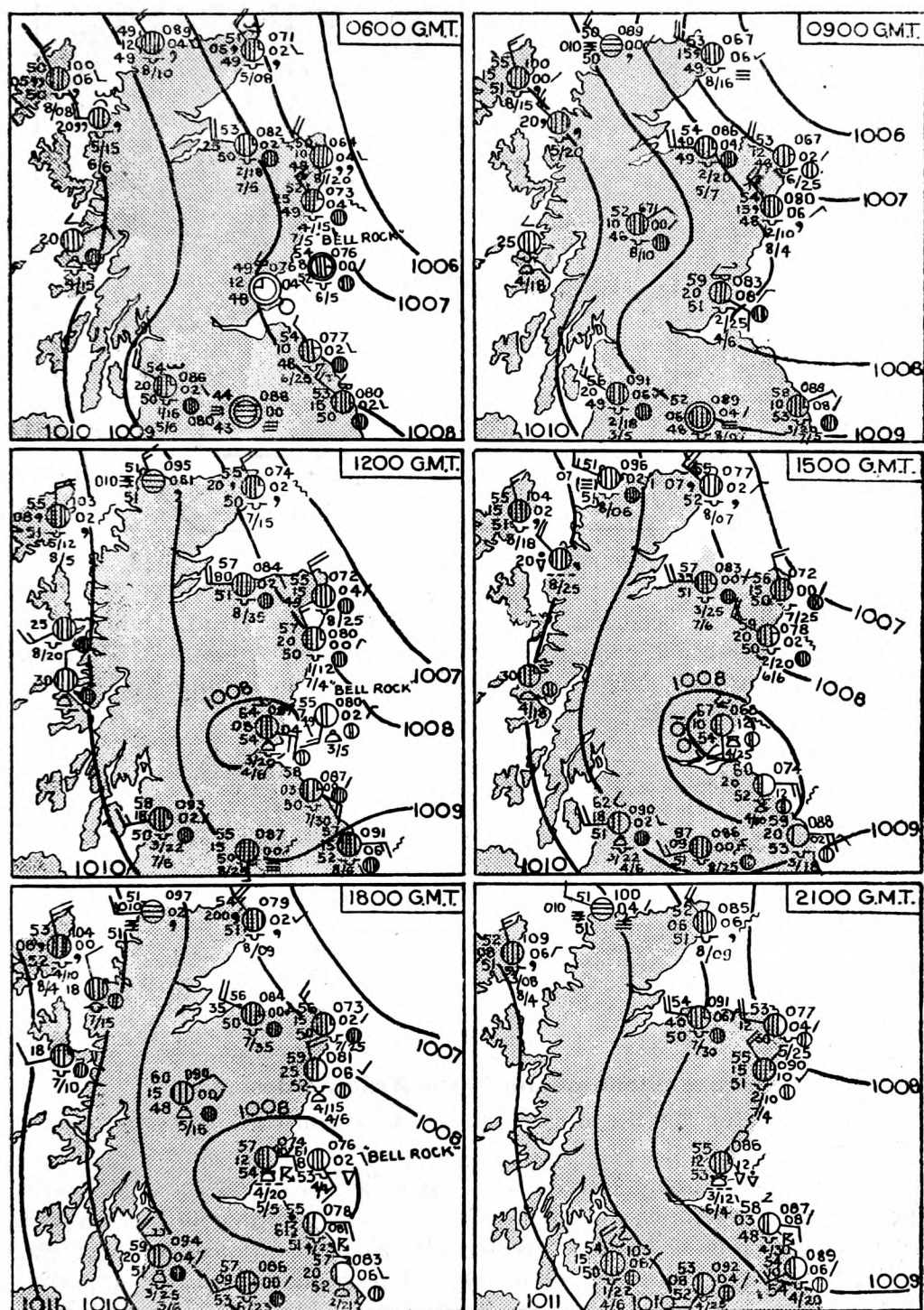


FIG. 1—SYNOPTIC CHARTS AT THREE-HOURLY INTERVALS, JULY 15, 1948

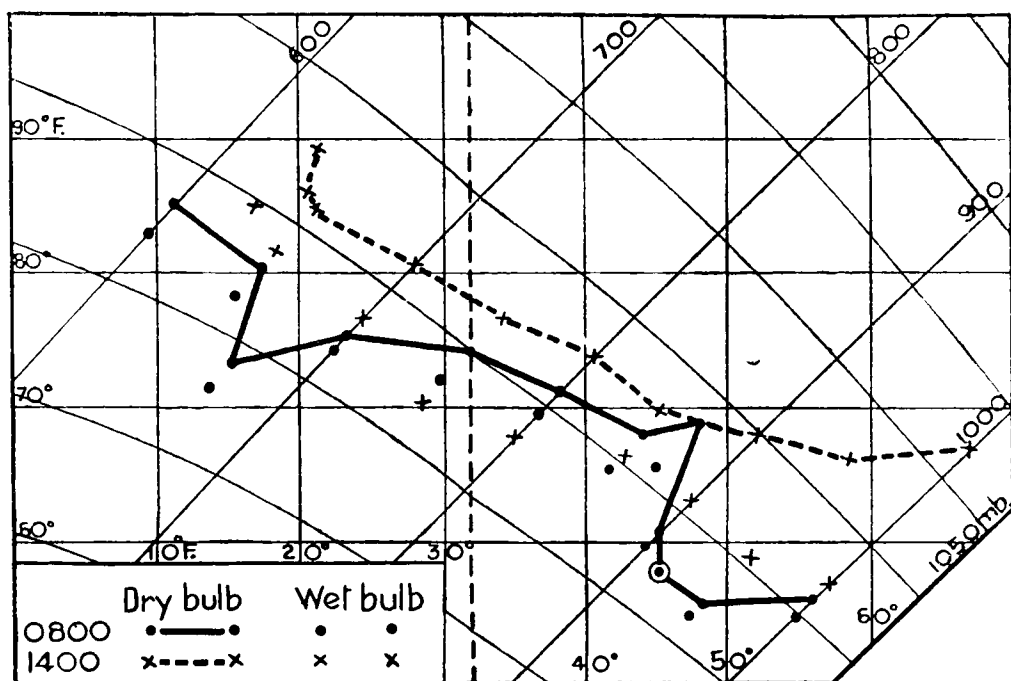


FIG. 2—UPPER AIR ASCENTS AT LEUCHARS, JULY 15, 1948

Thunderstorms also occurred at Donibristle, St. Abbs Head, Dunfermline and Dunbar. Hail accompanied the storm at Dunbar. A man was killed by lightning near Cortachy, Angus and a house was struck by lightning at Dundee.

Upper winds at Leuchars on July 15 were :—

Height	0800 G.M.T.		1400 G.M.T.	
	°true	kt.	°true	kt.
700	310	7	270	11
750	320	7	290	13
800	320	12	300	14
850	320	11	290	13
900	300	6	270	9
950	270	6	260	9

W. A. L. MARSHALL

September 15, 1948

A rare phenomenon in the Arabian desert

The snowfall illustrated in the photograph by Mr. J. Durward opposite occurred on January 27, 1937.

A depression, originally formed as a secondary over the North Sea on January 19 moved south-east to south-west Asia finally uniting on the 26th with a depression which moved southwards from the Kara Sea to near the Aral Sea. The formation and movement of this last depression had caused a partial disintegration of a large anticyclonic belt covering Russia and Siberia from the 20th to 24th.

As the low-pressure area moved eastwards a cold current of polar continental air from the Kirghiz steppe swept across Iraq and north-western Arabia and led to the snowfall illustrated.



Reproduced by courtesy of J. Durward

SNOW IN THE ARABIAN DESERT

(see opposite page)



WIDEAWAKES AT ASCENSION ISLAND

These birds form a danger to aircraft at Wideawake Field, Ascension Island. A similar danger exists with locusts in the Sudan.



Reproduced by courtesy of O. M. Ashford

CIRRUS OF AN APPROACHING WARM FRONT WITH A LAYER OF ALTOCUMULUS BENEATH

This photograph was taken in the evening of July 22, 1948; the warm front passed through station JIG before 0300 C.M.T. next morning. The altocumulus, which was present all day, was associated with a subsidence inversion typical of "ridge" weather.

Société Météorologique de France

We welcome the appearance of a new French quarterly meteorological journal, the *Journal Scientifique de la Météorologie*, published by the Societe Météorologique de France.

The first number of the new journal consists of 31 double crown octavo pages and contains papers by M. Nicolet on some fundamental problems in radiation, by Mme. Vassy on the effect of temperature on the ozone absorption bands in the visible spectrum, by M. Kivelovitch on vertical currents, and by M. Eyraud on the effects of vertical currents on aircraft.

The new journal will appear in addition to *La Météorologie*.

OBITUARY

Mr. G. A. Clarke.—We regret to report the death of Mr. G. A. Clarke, distinguished for his work in cloud photography, on February 13, 1949.

Mr. Clarke's name is associated in the minds of all meteorologists with the city of Aberdeen whose skyline he made so familiar to them in his cloud photographs, but actually he was an Englishman born in East Anglia on September 9, 1879.

He commenced meteorological work at Kew Observatory, but in 1903 migrated to Aberdeen to take charge of the University Observatory there under the direction of the Professor of Natural Philosophy. In 1921 he became a member of the staff of the Meteorological Office. He remained at Aberdeen Observatory until he retired in 1943.

Mr. Clarke's interest in clouds and cloud photography began while he was a young assistant at Kew Observatory. Later, he became one of the two or three leading exponents of the art of cloud photography. His cloud photographs adorned practically every meteorological book published in Great Britain in the last 30 years which had anything to do with cloud description or observation. Many of his photographs are the classic examples of the types of cloud they represent. The great "International Cloud Atlas" is full of them.

Clarke was not only a superb photographer of clouds : he had a deep and wide knowledge of cloud structure, the physical causes of clouds, and the meteorological situations in which they occurred. This knowledge is most fully shewn in his major publication "Clouds : a descriptive illustrated guide book to the observation and classification of clouds" published in 1920 with an introduction by Sir Napier Shaw. The coloured plates in this book were prepared from photographs coloured by Clarke who was a good artist. On the subject of cloud photography he wrote "Instructions for taking cloud photographs" published by the International Cloud Commission in 1923, and a paper on "Cloud photography" in the "Proceedings of the Seventh International Congress of Photography 1928". Other papers on clouds were his analysis of cloud distribution at Aberdeen during the years 1916-18, published as Meteorological Office *Professional Notes* No. 9, and some notes in the *Meteorological Magazine*.

On meteorological subjects other than clouds he wrote a report on the climate of Aberdeenshire for the meeting of the British Association held in the city in 1934, and a note in the *Quarterly Journal of the Royal Meteorological Society*

1921 on a remarkable pilot-balloon trajectory. He had a brisk, kindly manner and it was always a pleasure to visit him at the Observatory or at his home.

Clarke was a Fellow of the Royal Meteorological Society, and of the Royal Photographic Society whose medal for the best print in the Society's exhibition he won twice.

We extend to Mrs. Clarke our deepest sympathy.

NEWS IN BRIEF

Professor O. G. Sutton, F.R.S.

Prof. O. G. Sutton, Professor of Mathematics and Physics at the Military College of Science, and formerly of the Meteorological Office, Air Ministry, was elected a Fellow of the Royal Society on March 17, 1949.

Prof. Sutton is, of course, known to all meteorologists for his work on turbulence and diffusion in the lower atmosphere.

REVIEWS

Some speculations on the resistance to the motion of cumuliform clouds, by F. H. Schmidt. *Meded. ned. met. Inst., de Bilt*, Serie B, 1, Nr. 8. 8vo. $12\frac{1}{4}$ in. $\times$ $8\frac{3}{4}$ in., pp. 55. Rijksuitgeverij, The Hague, 1947, Price : Fl. 4,-.

In the "parcel" method, criteria of stability and instability are derived on the assumption that an isolated parcel of air could ascend or descend without causing any change in the environment. Bjerknæs and Petterssen, however, pointed out that this was not possible and that an ascending current must have its counterpart in a descending current, and in their "slice" method derived different criteria of stability and instability. In the present paper Dr. Schmidt, in addition to criticising the basic assumptions which Petterssen made in developing the "slice" method, points out that Petterssen's conclusions are based on an equation which has been derived from the combination of two equations which cannot be satisfied simultaneously and hence cannot possibly be correct.

To rectify this defect in the "slice" method Dr. Schmidt develops another method which he calls the "column" method based on considerations of the form drag in cumuliform cloud. To obtain a quantitative solution Dr. Schmidt makes several assumptions which are very approximate and are in some cases, inconsistent. The solution, however, appears to give results which can be used in practice and qualitatively, many of the results of the "column" method are similar to those of the "slice" method. Dr. Schmidt shews that with the "column" method it is possible for the first time to reconcile Kopp's measurements of temperature within clouds with Refsdal's theoretical results.

Later in the paper Dr. Schmidt utilises the results of work on axially symmetrical jets to discuss the problem of skin-friction drag of cumuliform clouds ascending in a homogeneous atmosphere, and then attempts to combine these results with his earlier calculations of form drag to obtain a qualitative picture of a cumuliform cloud. This is not very satisfactory, as in dealing with skin-friction drag it is necessary to assume that the cumuliform cloud is stationary whereas in dealing with form drag it is equally necessary to assume that the cumuliform cloud is not stationary.

R. FROST

A first book of meteorology, by Arthur J. Starr. 8vo. 8 in. $\times$ 5 $\frac{1}{4}$ in., pp. 86. *Illus.* Harrap & Co., Ltd., London, 1949. Price: 5s. od.

This little book gives a simple introduction to meteorology, assuming hardly any knowledge of physics. Within its limits it is accurate which is more than can be said of some books of this type. There are chapters on the atmosphere in general, winds, clouds, weather (formation of rain, snow, sleet, hail, thunder), fog and mist, pressure and temperature measurement, compilation of the synoptic chart, depressions and anticyclones, and weather forecasting. There is a useful appendix, with an indication of price, on instruments suitable for a school meteorological station.

It is scarcely correct to say that J. Bjerknes deduced the familiar frontal weather sequence from theory. The author was unfortunate in publication at the time of change of the international code; he gives the old code. More care might have been taken in proof reading.

This book costs twice as much as "Meteorology for pilots and navigators", which is of about the same level of difficulty but contains more information, though it is, perhaps, presented in a less attractive way.

G. A. BULL

Weather forecasting, by Inst. Cdr. S. W. C. Pack. 8vo. 9 $\frac{1}{4}$ in. $\times$ 6 in., pp. 192. *Illus.* Longmans, Green & Co., London, 1948. Price 25s. od.

The author states that he intends the book to provide an introduction to students who are about to specialise in meteorology and considers that it will also be of general interest to senior students in schools. The book covers the wide field of meteorology as it concerns weather forecasting, but perhaps too much emphasis at times is laid on the rules of forecasting rather than on the underlying physical processes. The general scope of the volume is probably more suitable for those taking the Civil Air Navigators' licences or the R.A.F. equivalent.

The book deals well with atmospheric stability and instability and the use of the tephigram in the prediction of convection cloud. Good diagrams give a clear expression to the chapter on the change of wind with height. The chapters on upper-level charts and forecasting in the tropics are very clearly explained.

The book is well produced and the diagrams and photographs throughout are clear and informative. However, it is considered that in an introduction to forecasting more emphasis should be laid on the convective, radiative and conductive processes as effecting the atmosphere and the importance of the sun's heating and the water vapour on the weather processes in the atmosphere. Also a fuller discussion on fundamental properties such as dry-bulb, dew-point and wet-bulb temperatures, etc., and their degree of conservatism for the various processes taking place in the atmosphere requires a place in a book on weather forecasting.

The book is not long and, although it is well produced, the price is considered rather excessive. It does not contain nearly as much information as the Meteorological Office publication "Meteorology for Aviators" which costs 7s. 6d. and the more advanced book "Meteorology, theoretical and applied" by Hewson and Long which costs \$4.75.

R. E. FARMS

Symposium on searchlights. 8vo. $9\frac{3}{4}$ in. $\times$ 6 in. pp. 164. *Illus.* Published by the Illuminating Engineering Society, Argus Press, London. 1948. Price : 17s. 6d.

This book contains six papers by different authors, dealing with various problems encountered in the design and use of searchlights during the war. Five of the papers were read before the Illuminating Engineering Society on April 15, 1947, and an account of the discussion which followed is also included.

Three papers cover various aspects of searchlight design, and include technical data of the types in current use. It is interesting to see that the carbon arc is still used almost exclusively as a light source, though invented over a century ago. Several searchlights for aircraft use are described which produced, for short periods, intensities little inferior to those of ground searchlights, *i.e.* several hundred million candles.

After an informatory paper on the photometry of searchlights come two papers of more direct interest to meteorologists, dealing with the visibility of targets in a searchlight beam. Both horizontal (naval) and anti-aircraft beams are considered, and the useful range of various searchlights is calculated for a variety of targets and atmospheric conditions. The scatter coefficient of the atmosphere is found to be the overriding factor in limiting the range, so much so that even the most powerful naval searchlight is almost useless if the meteorological visibility is less than about 3,000 yd.

Meteorologists have long used searchlights to measure cloud height, and more recently to measure visibility. Future work in these fields will probably demand bigger and better searchlights, and many of the problems which will then arise will be found already answered in this symposium.

J. R. BIBBY

Everybody's weather book, by Reginald M. Lester. 16mo. 8 in. $\times$ 5 in. *Illus.* xx + 235. Sampson Low, Marston & Co., Ltd., London. 1948. Price 15s. 0d.

This small book by Mr. Lester sets out to introduce to the man-in-the-street the general mechanism of the weather and how it is observed and forecast. It makes no pretensions of being a text-book—indeed it is neither scientific nor accurate—and only describes the more elementary features of the weather, and just touches the fringe of frontal and air-mass analysis in a few odd pages.

In the beginning Mr. Lester describes briefly how weather information is collected in this country, and then tries to interest the reader in recognition of various types of weather sequence, in the types of clouds and the behaviour of the barometer during the sequence. He then considers some of the more unusual weather phenomena such as exceptionally heavy rains and auroras, and goes on to discuss the importance of weather and its irregularities to plants, birds and insects, to the farmer, and the water-engineer. He closes with chapters on weather over the oceans and over the continents, a discussion of the relation of the sun-spot cycle with weather “cycles”, and a final description of what an amateur meteorologist like himself can learn from such observations as rainfall, pressure, and temperature.

The whole book is written in a gossipy fashion even including the rumour of seaweed in the forecast room at the Central Forecast Office and such old weather saws as:

“ Rain before seven,
Fine before eleven.”

Particularly interesting were the "Folkestone pillars" ("a series of towering conical cloud-banks rising up from an especially dense base"—apparently altocumulus castellatus) which are "invariably" followed by rain throughout the next day over the Bristol Channel, although the "showery type of weather does not usually set in until the next day but one" when they appear off the Kentish or Essex coast. It is interesting also to learn of the danger of being suddenly crushed to death by the force of cosmic radiation in the stratosphere.

Some of the cloud photographs have not reproduced too well: those of cirrocumulus and cumulonimbus are unrecognisable. Mr. Lester is unfortunate, too, in that some of his tables of cloud forms are now out of date and there is a mistake in his conversion of degrees Centigrade to Fahrenheit.

P. B. SARSON

BOOKS RECEIVED

Apia Observatory, Annual Report for 1939. New Zealand Department of Scientific and Industrial Research. 8vo. $9\frac{3}{4}$ in. $\times$ $6\frac{1}{2}$ in. pp. iv + 149. Wellington, 1948. Price: 5s.

Observations made at the Royal Magnetic and Meteorological Observatory at Batavia, by H. P. Berlage, Jr. Vol. LXIII C, 1940 : Results of meteorological observations for the period 1866-1940. 4to. $12\frac{1}{2}$ in. $\times$ $9\frac{3}{4}$ in. pp. 43. Surabaya [1948].

Annuaire. 97^{ième} année. A: *Météorologie* 1945. Koninklijk Nederlands Meteorologisch Instituut. 4to. $13\frac{1}{2}$ in. $\times$ $9\frac{1}{2}$ in. pp. 82. Staatsdrukkerij- en Vitgererijbedrijf. The Hague, 1948. Price : fl. 2.60.

ERRATUM

April 1949, PAGE 100, line 47 : *for* equator³ *read* equator².

WEATHER OF MARCH 1949

After a deep depression had moved south-eastwards across the northern part of the North Sea during the early hours of the 1st, an Atlantic anticyclone advanced to western Ireland by the morning of the 2nd, but soon moved away southwards. On the 7th and 8th a depression moved south-eastwards not far to the south-west of the British Isles, and others moved eastwards not far to the north of Scotland on the 13th and south-eastwards across the Orkneys on the 17th. Then for several days an anticyclone persisted off our south-west coasts, and this spread over the British Isles on the 22nd. Pressure was rather high during the rest of the month, although the highest pressure was generally further to the north or north-east.

Mean pressure for the month was above 1020 mb. from Poland westwards across England and Ireland nearly to 50°W., and between 1015 mb. and 1020 mb. over most of North America. It was above normal over most of Europe and the north-eastern part of the North Atlantic, by more than 10 mb. in Ireland and the Hebrides and for more than a thousand miles west-south-westward of Ireland ; it was generally about normal in North America.

The weather over the British Isles was generally dry ; there was less sunshine than usual in the eastern districts of England while it was very sunny locally in the north-west of the British Isles. Cold weather prevailed during the first 12 days but from the 13th to the 26th it was generally warm. The closing days were warm in the west but cool elsewhere.

On the 1st a deep depression over Denmark moved away eastwards ; in its rear the northerly gradient was steep and northerly gales in the North Sea caused exceptionally high tides in the Thames estuary and consequent severe flooding. Subsequently an anticyclone moved south-south-east from north-west of Scotland giving a short period of cold, sunny weather. On the 3rd a trough of low pressure moving north-east caused rain in many districts but the rain did not reach most of England until night. An unsettled cold spell ensued with troughs from Atlantic depressions moving east over the country ; precipitation occurred at times, rainfall amounting to more than 1 in. locally on each day from the 3rd to the 6th. Snow occurred at times, being widespread on the 5th ; it was 4 in. deep at Blackpool on the 5th and 3 in. at Whipsnade on the 6th and 7th. On the 8th and 9th a depression off south-west Ireland moved slowly south ; snow occurred rather widely and level snow was 3 in. deep at Harrogate on the 8th. At Malham Tarn (1,297 ft. above M.S.L.) in West Yorkshire level snow was 6 in. deep on the 8th with drifts of 18 in., while on the 9th there were drifts of 5 ft. In the rear of this depression a belt of high pressure developed to the north of Scotland and moved south giving a fair day in most parts on the 10th, but a trough off our north-west coasts moving south-east caused rain generally and gales at a few exposed stations in Scotland on the 11th and 12th. Subsequently a deep depression over Thorshaven moved east to the Baltic, while secondaries moved rapidly east or south-east over the British Isles causing local gales and some precipitation on the 13th and 14th. Thereafter pressure was high on the Atlantic and a depression south-west of Iceland moved south-east to Denmark and thence to central Europe ; showery weather prevailed in the British Isles, with local gales but long bright periods. On the 20th and 21st troughs moving east over the country were associated with fairly general rain.

A change of type occurred on the 22nd when the anticyclone off our south-west coasts moved north-east and subsequently east to central Europe. Dry, mild, mainly fair weather prevailed, apart from fog, until the 26th. On the 26th and following days a new anticyclone south of Iceland moved east to Russia ; weather continued dry, but dull and cold, with considerable fog in eastern and central districts but warm and very sunny locally in the west. At Eskdalemuir, for example, the maximum temperature was 63°F. on the 30th and 65°F. on the 31st, while the corresponding values at Gorleston were 42°F. and 41°F. At Eskdalemuir too, the total sunshine for the last two days was 20.6 hr.

The general character of the weather is shown by the following provisional figures :—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	69	18	—0.7	66	—6	99	32
Scotland	67	15	+0.1	76	—3	110	32
Northern Ireland..	64	24	+1.4	85	—6	110	33

RAINFALL OF MARCH 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	·84	46	<i>Glam.</i>	Cardiff, Penylan ..	1·87	59
<i>Kent</i>	Folkestone, Cherry Gdn.	·92	42	<i>Pemb.</i>	St. Ann's Head ..	2·28	84
<i>"</i>	Edenbridge, Falconhurst	1·19	48	<i>Card.</i>	Aberystwyth ..	2·34	85
<i>Sussex</i>	Compton, Compton Ho.	1·97	71	<i>Radnor</i>	Tyrmynydd ..	3·41	64
<i>"</i>	Worthing, Beach Ho.Pk.	1·23	64	<i>Mont.</i>	Lake Vyrnwy ..	2·46	54
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	2·10	102	<i>Mer.</i>	Blacnau Festiniog ..	5·64	65
<i>"</i>	Bournemouth ..	1·48	64	<i>Carn.</i>	Llandudno ..	1·66	82
<i>"</i>	Sherborne St. John ..	1·51	67	<i>Angl.</i>	Llanerchymedd ..	2·40	81
<i>Herts.</i>	Royston, Therfield Rec.	1·15	63	<i>I. Man.</i>	Douglas, Borough Cem.	4·05	137
<i>Bucks.</i>	Slough, Upton ..	1·27	72	<i>Wigtown</i>	Port William, Monreith	2·68	94
<i>Oxford</i>	Oxford, Radcliffe ..	1·70	103	<i>Dumf.</i>	Dumfries, Crichton R.I.	1·59	53
<i>N'hant.</i>	Wellingboro', Swanspool	1·38	77	<i>"</i>	Eskdalemuir Obsy. ..	2·49	51
<i>Essex</i>	Shoeburyness ..	·75	56	<i>Roxb.</i>	Kelso, Floors ..	1·09	56
<i>Suffolk</i>	Campsea Ashe, High Ho.	·71	42	<i>Peebles</i>	Stobo Castle ..	1·54	53
<i>"</i>	Lowestoft Sec. School ..	1·49	93	<i>Berwick</i>	Marchmont House ..	1·35	51
<i>"</i>	Bury St. Ed., Westley H.	·99	52	<i>E. Loth.</i>	North Berwick Res. ..	·87	46
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·31	69	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	·80	41
<i>Wilts.</i>	Bishops Cannings ..	1·26	56	<i>Lanark</i>	Hamilton W. W., T'nhill	1·44	52
<i>Dorset</i>	Creech Grange ..	1·47	52	<i>Ayr</i>	Colmonell, Knockdolian	2·49	74
<i>Devon</i>	Beaminster, East St. ..	1·43	49	<i>"</i>	Glen Afton, Ayr San ..	..	..
<i>"</i>	Teignmouth, Den Gdns.	1·21	47	<i>Bute</i>	Rothsay, Ardenraig	3·30	92
<i>"</i>	Cullompton ..	1·65	60	<i>Argyll</i>	L. Sunart, Glenborrodale	4·37	79
<i>"</i>	Barnstaple, N. Dev. Ath.	1·85	71	<i>"</i>	Poltalloch ..	3·52	92
<i>"</i>	Okehampton, Uplands	1·74	42	<i>"</i>	Inverary Castle ..	4·91	77
<i>Cornwall</i>	Bude School House ..	1·73	71	<i>"</i>	Islay, Eallabus ..	3·68	96
<i>"</i>	Penzance, Morrab Gdns.	1·81	57	<i>"</i>	Tiree ..	3·15	94
<i>"</i>	St. Austell, Trevarna ..	2·45	71	<i>Kinross</i>	Loch Leven Sluice ..	1·40	47
<i>"</i>	Scilly, Tresco Abbey ..	1·75	67	<i>Fife</i>	Leuchars Airfield ..	1·32	68
<i>Glos.</i>	Cirencester ..	1·79	77	<i>Perth</i>	Loch Dhu ..	..	..
<i>Salop.</i>	Church Stretton ..	2·00	83	<i>"</i>	Crieff, Strathearn Hyd.	1·64	51
<i>"</i>	Cheswardine Hall ..	2·73	129	<i>"</i>	Blair Castle Gardens ..	1·99	72
<i>Staffs.</i>	Leek, Wall Grange P.S.	2·15	79	<i>Angus</i>	Montrose, Sunnyside ..	1·25	60
<i>Worcs.</i>	Malvern, Free Library	1·22	63	<i>Aberd.</i>	Balmoral Castle Gdns. ..	1·55	54
<i>Warwick</i>	Birmingham, Edgbaston	1·57	82	<i>"</i>	Dyce, Craibstone ..	2·74	103
<i>Leics.</i>	Thornton Reservoir ..	1·84	100	<i>"</i>	Fyvie Castle ..	2·77	102
<i>Lincs.</i>	Boston, Skirbeck ..	·94	60	<i>Moray</i>	Gordon Castle ..	2·80	121
<i>"</i>	Skegness, Marine Gdns.	·74	45	<i>Nairn</i>	Nairn, Achareidh ..	1·92	104
<i>Notts.</i>	Mansfield, Carr Bank ..	1·05	50	<i>Inv's</i>	Loch Ness, Foyers ..	2·64	82
<i>Ches.</i>	Bidston Observatory ..	2·09	110	<i>"</i>	Glenquoich ..	5·44	56
<i>Lancs.</i>	Manchester, Whit. Park	1·77	78	<i>"</i>	Fort William, Teviot ..	4·24	63
<i>"</i>	Stonyhurst College ..	2·44	66	<i>"</i>	Skye, Duntuiln ..	3·08	70
<i>"</i>	Blackpool ..	1·98	83	<i>R. & C.</i>	Ullapool ..	1·78	44
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·15	64	<i>"</i>	Applecross Gardens ..	3·89	83
<i>"</i>	Hull, Pearson Park ..	1·06	58	<i>"</i>	Achnashellach ..	6·52	96
<i>"</i>	Felixkirk, Mt. St. John	1·52	77	<i>"</i>	Stornoway Airfield ..	2·57	66
<i>"</i>	York Museum ..	1·45	86	<i>Suth.</i>	Lairg ..	3·11	100
<i>"</i>	Scarborough ..	1·06	59	<i>"</i>	Loch More, Achfary ..	6·57	102
<i>"</i>	Middlesbrough ..	1·02	65	<i>Caith.</i>	Wick Airfield ..	3·48	153
<i>"</i>	Baldersdale, Hury Res.	1·09	35	<i>Shetland</i>	Lerwick Observatory ..	3·52	111
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	·69	33	<i>Ferm.</i>	Crom Castle ..	2·32	75
<i>"</i>	Bellingham, High Green	·85	29	<i>Armagh</i>	Armagh Observatory ..	2·11	90
<i>"</i>	Lilburn Tower Gdns. ..	·83	31	<i>Down</i>	Seaforde ..	2·03	70
<i>Cumb.</i>	Geltsdale ..	1·33	48	<i>Antrim</i>	Aldergrove Airfield ..	2·19	87
<i>"</i>	Keswick, High Hill ..	1·28	28	<i>"</i>	Ballymena, Harryville ..	2·63	83
<i>"</i>	Ravenglass, The Grove	2·84	92	<i>L'derry</i>	Garvagh, Moneydig ..	2·79	89
<i>Mon.</i>	Abergavenny Larchfield	1·50	49	<i>"</i>	Londonderry, Creggan	3·39	106
<i>Glam.</i>	Ystalyfera, Wern House	3·29	61	<i>Tyrons</i>	Omagh, Edenfel ..	2·62	83

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, NOVEMBER 1948

STATIONS	PRESSURE		TEMPERATURES										REL- ATIVE HUM- IDITY	PRECIPITATION			BRIGHT SUNSHINE	
	Mean of day M.S.L.	Diff. from normal	Absolute		Mean values						Total	Diff. from normal		Days	Daily Mean	Per- centage of possible		
			Max.	Min.	°F.	°F.	Min.	1 2	Max.	Diff. from normal			°F.				°F.	
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	in.	in.	hr.	%		
Gibraltar ..	1022.8	+8.9	61	25	50.5	40.3	45.4	42.9	+1.6	42.9	7.3	93	-0.63	9	2.3	26		
Malta ..	1024.1	+6.1	75	50	67.2	58.3	62.7	59.6	+2.7	59.6	6.8	88	—	2	4.5	44		
St. Helena ..	1020.4	+4.5	77	44	67.1	56.3	61.7	54.9	-2.2	54.9	6.2	72	—	15	5.9	58		
Freetown, Sierra Leone	1016.6	+0.1	69	52	65.4	55.0	60.2	74.5	+1.5	74.5	7.0	88	-0.75	6	—	—		
Lagos, Nigeria ..	1011.5	+1.4	89	70	83.5	72.8	79.1	76.8	—	76.8	8.2	85	—	9	—	—		
Kaduna, Nigeria ..	1014.3	+0.6	91	68	87.9	70.4	79.1	76.8	-2.6	76.8	8.2	85	—	7	5.9	50		
Chileka, Nyasaland	1014.3	+0.6	97	60	87.1	67.6	77.3	67.2	-0.4	67.2	5.3	61	+0.56	9	6.7	52		
Lusaka, Rhodesia ..	1012.1	+0.8	90	55	81.9	63.3	72.6	63.8	-1.6	63.8	7.0	71	+1.57	11	6.1	48		
Salisbury, Rhodesia ..	1013.8	+0.6	89	48	80.0	59.4	69.7	60.2	-0.5	60.2	4.0	64	+1.45	10	6.1	47		
Cape Town	—	—	92	49	—	—	—	—	—	—	—	—	—	5	—	—		
Germiston, South Africa	1014.3	+1.4	81	43	74.4	54.0	64.2	55.1	-1.7	55.1	4.7	64	-0.78	14	8.4	63		
Mauritius ..	1014.0	+0.6	91	63	84.7	69.1	76.9	69.7	+3.4	69.7	5.3	85	+2.99	6	5.9	53		
Calcutta, Alipore Obsy.	1010.0	-2.0	95	71	88.7	75.8	82.3	74.1	+1.7	74.1	5.1	77	+4.09	5	7.9	71		
Madras ..	1011.2	-0.1	94	72	86.4	74.8	80.6	75.8	+1.7	75.8	6.7	88	-5.07	13	7.4	64		
Colombo, Ceylon ..	1010.7	+0.7	88	71	86.4	73.5	79.9	74.6	-0.1	74.6	6.4	91	+0.56	18	7.3	62		
Singapore ..	1010.7	+1.3	91	72	86.2	73.9	80.1	75.7	-0.5	75.7	8.5	86	+1.96	22	—	—		
Hongkong ..	1020.0	+2.4	80	53	72.9	61.6	67.3	60.4	-2.3	60.4	—	68	-1.59	4	7.1	64		
Sydney, N.S.W. ..	1011.9	-1.9	97	51	71.9	58.9	65.4	59.6	-1.6	59.6	6.1	61	-2.03	12	8.1	58		
Melbourne ..	1010.4	-4.0	89	41	70.4	49.4	59.9	53.6	-1.4	53.6	6.2	55	-0.27	12	6.9	49		
Adelaide ..	1012.0	-3.3	92	43	73.8	53.5	63.7	55.2	-3.3	55.2	5.7	52	+0.08	11	7.9	57		
Perth, W. Australia	1012.0	—	97	44	75.6	54.6	65.1	58.4	-1.0	58.4	5.5	56	+1.17	6	9.4	68		
Coolgardie ..	1012.2	-1.2	101	39	82.1	53.4	67.7	65.2	-3.0	65.2	4.0	62	-0.49	2	—	—		
Brisbane ..	1012.9	-1.7	93	56	82.0	65.0	73.5	65.2	0.0	65.2	5.2	62	-2.38	7	9.1	71		
Hobart, Tasmania ..	1007.5	-2.1	76	39	63.2	46.4	54.8	50.4	-2.4	50.4	8.0	61	+0.03	19	6.1	42		
Wellington, N.Z. ..	1011.6	-0.5	71	41	61.8	48.6	55.2	52.7	-0.4	52.7	8.3	78	+0.75	13	6.3	44		
Suva, Fiji ..	1009.1	-2.0	86	69	82.4	72.6	77.5	74.3	+0.4	74.3	8.0	85	-4.29	21	4.7	36		
Apia, Samoa ..	1008.6	-0.5	89	71	85.9	73.9	79.9	77.6	+0.2	77.6	6.0	78	+5.63	22	7.4	58		
Kingston, Jamaica ..	1012.3	-0.1	92	70	89.6	72.7	81.1	74.9	+1.8	74.9	2.9	77	-0.54	7	8.1	72		
Grenada, W. Indies	—	—	88	72	85.0	76.0	80.5	76.7	+1.0	76.7	8.3	80	+0.79	24	—	—		
Toronto ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Winnipeg ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
St. John, N.B. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Victoria, B.C. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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RELATION OF SURFACE WINDS TO PRESSURE GRADIENTS

BY C. S. DURST, B.A.

During the war it was desired to know what was the most probable surface wind for a given geostrophic wind. A certain amount of information on this subject is given by Shaw* but there does not seem to be available in meteorological literature a comparison of the frequencies of different wind speeds with the associated pressure gradients. To remedy this lack, certain months and hours were examined by using the winds recorded at Gorleston and comparing these with the simultaneous pressure gradients measured off the working charts. The measurements of geostrophic winds were made by Mr. C. F. J. Jestico and much of the calculation and tabulation was done by him.

The data were arranged according as the pressure gradients were on shore (between NE. and SE.) or off shore (between SW. and NW.). The months used were May, June, July and August 1936-40 representing summer, using the two hours 0100 and 1300 G.M.T. For winter the months January and December 1936-40 were used and the four hours 0100, 0700, 1300 and 1800 were included.

In addition the Beaufort letters of past weather at Mildenhall during the 6 hours before each synoptic hour were tabulated as giving a general indication of the state of the sky over the land since it was felt that this would show the relation of the development of land and sea breeze to convection.

The data were discussed by making out the frequencies of the ratio of surface wind to geostrophic wind. These ratios were plotted and are shown in Figs. 1 and 2. The modes of the curves in these diagrams were then assembled in Tables I and II.

Table I indicates the diurnal variation and Table II the relation of the ratio to the steepness of gradient.

The broad conclusions are:—

(1) On-shore winds are approximately four fifths the geostrophic wind in winter and two thirds in summer.

*SHAW, SIR NAPIER; *Manual of Meteorology*. Vol. IV. *Meteorological calculus: Pressure and wind*. Cambridge, revised edition, 1931.

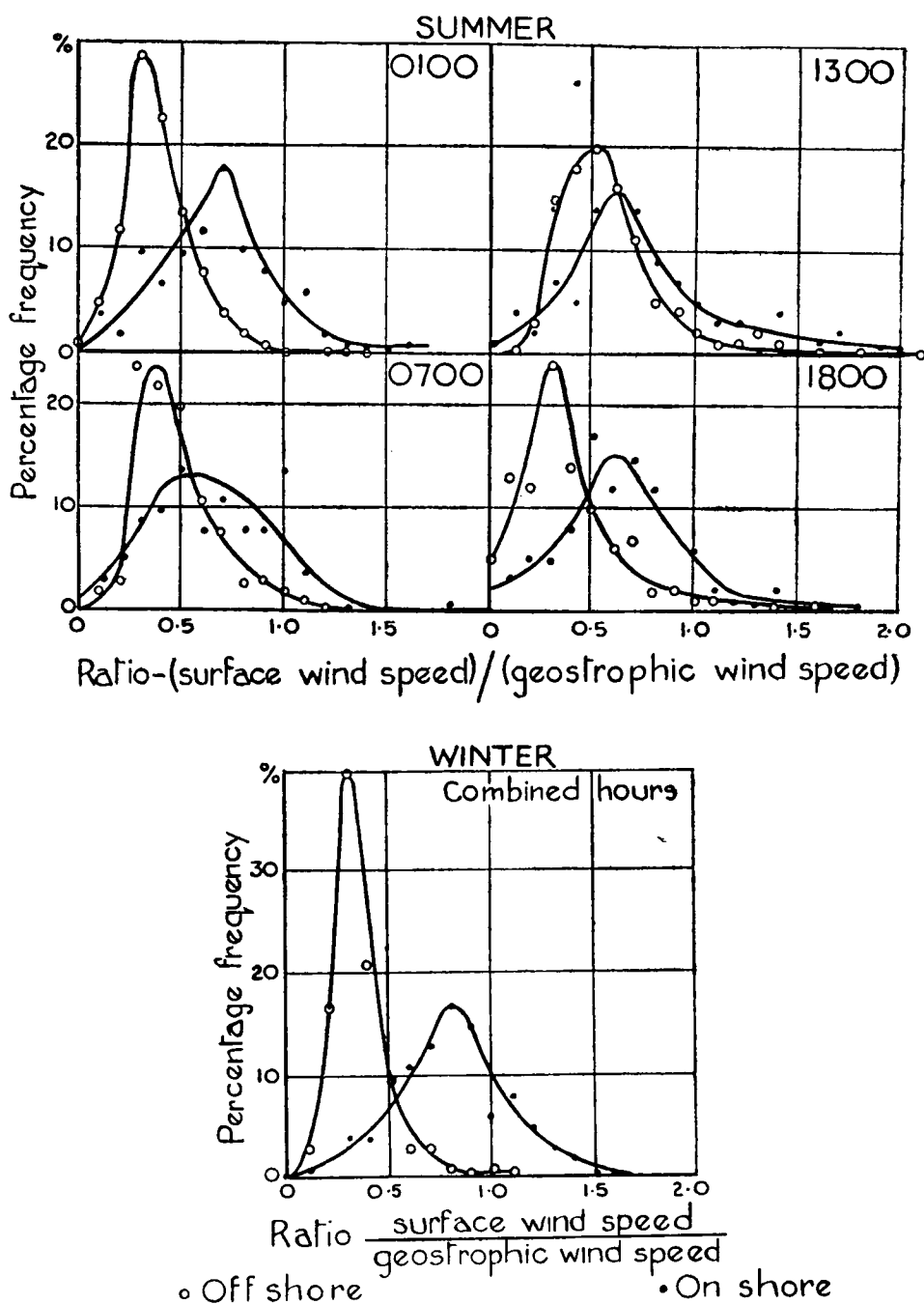


FIG. 1—SEASONAL AND DIURNAL VARIATION OF RATIO OF SURFACE TO GEOSTROPHIC WIND

- (2) There is practically no diurnal variation in the ratio in winter.
- (3) Off-shore winds are approximately one third of the geostrophic wind in winter and just over two fifths in summer.
- (4) In summer there is a marked diurnal variation. The off-shore winds are relatively weak at night and relatively strong in the day-time.
- (5) With a geostrophic speed of less than 20 m.p.h., the on-shore wind has a wide range of speed and may even exceed the geostrophic; the off-shore wind is less scattered at night but has about the same scatter in the day-time.

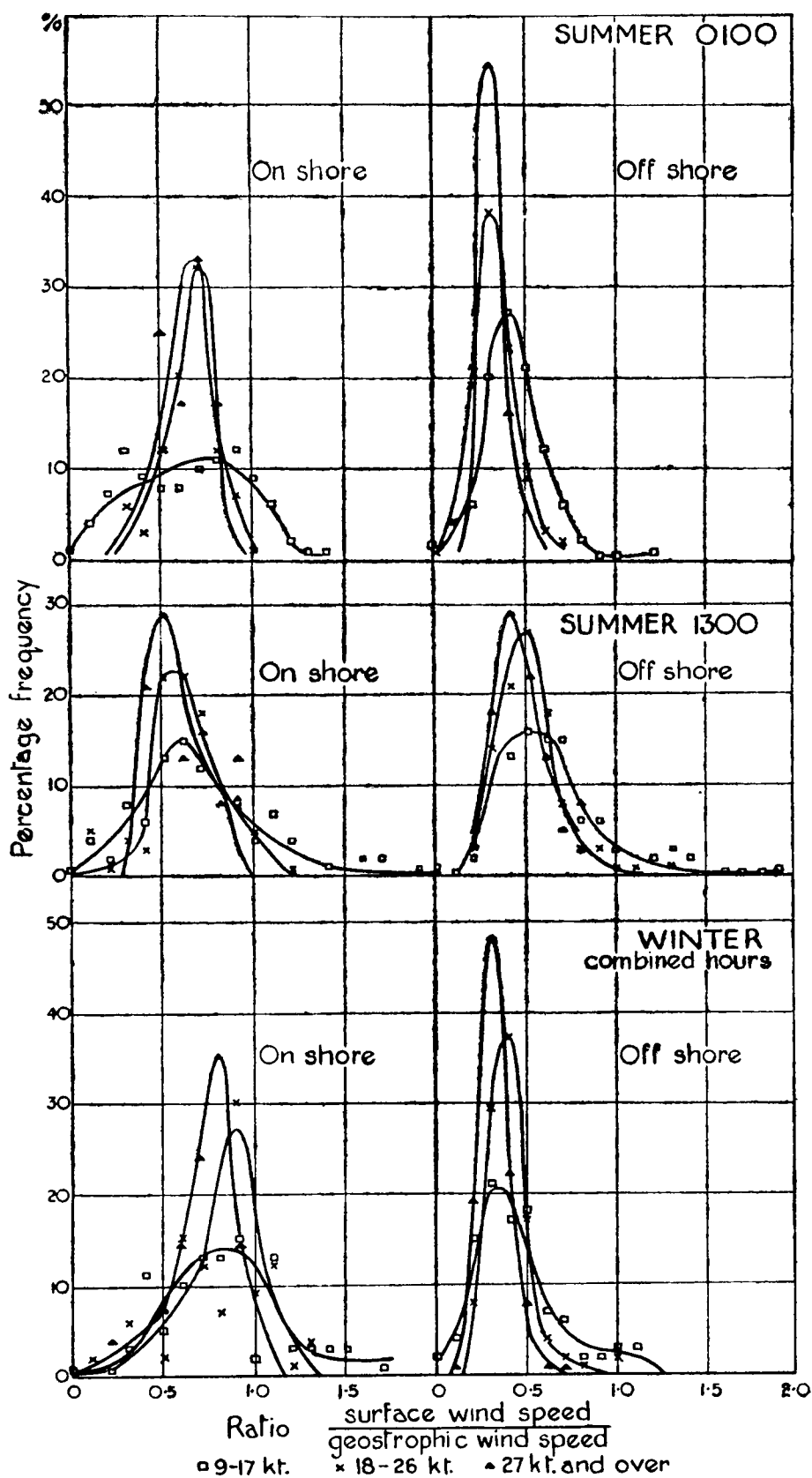


FIG. 2—VARIATION OF RATIO OF SURFACE TO GEOSTROPHIC WIND WITH WIND SPEED

TABLE I—DIURNAL VARIATION OF RATIO: (SURFACE WIND)/(GEOSTROPHIC WIND)

	Time of observation (G.M.T.)							
	0100		0700		1300		1800	
	on shore	off shore	on shore	off shore	on shore	off shore	on shore	off shore
Winter Dec., Jan.	0.75	0.32	0.82	0.32	0.75	0.35	0.83	0.30
Summer May, June, July, Aug.	0.65 0.70	0.39 0.35	0.62 0.75	0.52 0.41	0.63 0.92	0.58 0.49	0.64 0.63	0.46 0.30
All summer months	0.67	0.36	0.65	0.45	0.65	0.52	0.63	0.38

TABLE II—VARIATION OF THE RATIO WITH WIND SPEED

	Time	9-17 kt. (10-19 m.p.h.)		18-26 kt. (20-29 m.p.h.)		27-35 kt. (30-39 m.p.h.)	
		on shore	off shore	on shore	off shore	on shore	off shore
	G.M.T.						
Winter Dec., Jan.	{ 0100 1300	0.87 0.75	0.40 0.37	0.88 0.82	0.44 0.36	0.77 0.77	0.26 0.33
Summer May-Aug.	{ 0100 1300	0.65 0.66	0.42 0.59	0.68 0.60	0.32 0.49	(0.73) 0.55	0.32 0.45

In Table III the modes are given of the ratios when the skies over the land were mainly clear, broken, and overcast.

The state of the sky inland is no great help in deducing the surface wind from the geostrophic wind in winter, but in summer the more cloudy the mid-day sky the more nearly will the on-shore wind approach the geostrophic.

The data so arranged gave no information on the direction of surface wind in relation to the pressure gradient. Table IV sets out the mean values of the geostrophic wind together with its standard scalar deviation and the vector mean values of the surface wind together with its standard vector deviation.

TABLE III—VARIATION OF MOST PROBABLE VALUE OF THE RATIO WITH THE VARIOUS STATES OF THE SKY OVER THE LAND

	Time	Mainly clear sky		Broken skies		Overcast	
		on shore	off shore	on shore	off shore	on shore	off shore
	G.M.T.						
Winter Dec., Jan.	All hours	0.72	0.32	0.82	0.34	0.80	0.32
Summer May-Aug.	{ 0100 1300	0.65 0.54	0.39 0.43	0.58 0.63	0.34 0.55	0.75 0.75	0.36 0.49

TABLE IV—MEAN VALUES OF SURFACE AND GEOSTROPHIC WINDS

	Time	No. of obs.	Geostrophic wind	Standard deviation	Surface wind*	Standard vector deviation
	G.M.T.		kt.	kt.	° kt.	kt.
Winter						
Off shore	0100	76	27	12	33 8	8
	0700	67	28	17	33 8	5
	1300	83	29	14	30 10	7
	1800	68	31	10	36 9	8
	All hours	294	28	14	32 9	7
On shore	0100	53	20	10	24 14	10
	0700	51	20	10	24 14	10
	1300	48	20	8	25 15	8
	1800	53	20	10	24 16	9
	All hours	205	20	10	24 14	10
Summer						
Off shore	0100	204	17	8	37 6	4
	1300	187	18	9	39 7	8
On shore	0100	81	15	7	39 9	6
	1300	100	15	7	45 8	7

*Angle given is that between gradient and surface wind directions.

Thus it is seen the surface wind on the average lies at an angle of 30–40° to the isobars with off-shore winds, but in winter with on-shore winds it is only 24° to the isobars. The correlation coefficient of the surface wind with the geostrophic wind is comparatively small, being no more than about 0·4 or 0·5 with both on-shore and off-shore winds.

DEW-POINT TABLES—A NEW PROCEDURE

By E. G. BILHAM, B.Sc., D.I.C.

Meteorological Office practice for the computation of vapour pressure and thence of dew point and relative humidity from the dry-bulb and wet-bulb temperature, is based on the Regnault formula

$$x = f - Ap(t - t')$$

where x = vapour pressure at the time of observation
 f = the saturation vapour pressure at the temperature t' of the wet bulb
 p = the pressure of the air
 t = the temperature of the dry bulb
 t' = the temperature of the wet bulb
 A = a constant depending on the speed of the air past the wet bulb and on the scale of temperature used.

For observations in Fahrenheit degrees made with an aspirated psychrometer or with an aircraft psychrometer flying near the surface, the value adopted for Ap is 0·37 when the wet-bulb temperature is above 32°F. and 0·33 when the wet-bulb temperature is 32°F. or below. Under the latter conditions the wet bulb is assumed to be covered with ice.

Confining attention for the moment to the case of wet-bulb readings above freezing point, the multiplier of $(t - t')$ may be written in the form 0·37 $p/1000$,

p being the pressure at the place of observation in millibars. If f is also expressed in millibars, the formula gives the vapour pressure x in millibars. From this, the dew point is at once obtained by ascertaining, from a table of saturation vapour pressures, the temperature t_d for which x is the saturation pressure over water.

When readings are taken near sea-level it is usual to disregard the day-to-day variations of p , the barometric pressure, and to base the computation on the assumption that p is constant and equal to 1000 mb. It is clearly necessary, however, to take the variations of p into account when readings are made from an aircraft flying at a substantial height. At the pressure of 500 mb., which is normally reached in ascents during meteorological reconnaissance flights, the value of the multiplier $Ap/1000$ is only half its value at ground level, and a table computed on the assumption $p = 1000$ mb. is therefore inapplicable. The main object of this note is to describe a new procedure for taking account of the variation of pressure.

Hitherto it has been the practice to use separate relative humidity tables for levels 1000 mb., 900 mb., 800 mb., . . . 400 mb. The dew point, if required, was then derived from a table with the dry bulb and the relative humidity as arguments. The aircraft humidity tables in use prior to January 1949* were based on the definition:—

$$\text{Relative humidity} = \frac{\text{actual vapour pressure}}{\text{saturation vapour pressure at dry-bulb temperature}} \times 100,$$

the saturation vapour pressure referring to ice at temperatures below freezing point. By a resolution at Washington, 1947, supercooled water is substituted for ice as the basis of computation with effect from January 1, 1949. For this reason, and also because the Conference of Directors had recommended the adoption of the new Goff-Gratch tables of saturation vapour pressures as the basis of hygrometric tables, it became necessary *inter alia* to recompute the tables for use with aircraft observations.

When the matter was examined it was realised that there were substantial advantages in using the wet bulb rather than the dry bulb as the primary argument in the construction of humidity tables. One very obvious advantage—though perhaps a minor one—is that the range of temperature to be covered would be much reduced because even in the tropics wet-bulb readings exceeding 85°F. are rare. A much more important advantage becomes evident when we consider the correction for pressure. Suppose we have constructed a “basic” vapour-pressure or dew-point table corresponding to $p = 1000$ mb. with wet bulb and depression of wet bulb as arguments. We see at once from Regnault’s formula that we can use this same table for a pressure of 500 mb. by merely halving the observed depression of wet bulb before entering the table. Similarly for any pressure level, p , the basic table is valid if we replace the actual depression of wet bulb by the “adjusted” depression $(t - t')p/1000$.

Instead, therefore, of a whole series of tables computed for different values of p , we need only one table (corresponding to $p = 1000$) plus a subsidiary table for obtaining the “adjusted” depression from the observed values of actual depression and pressure.

*London, Meteorological Office. Tables for obtaining values of relative humidity of the air from readings of an aircraft aneroid barometer and aircraft psychrometer in degrees Fahrenheit. London, 2nd edn., 1945.

This procedure can be used for the construction of tables for deriving either the vapour pressure or the dew point from aircraft observations of wet bulb and depression of wet bulb. The basic table can also obviously be used, without any adjustment of the depression of wet bulb, for surface observations with an aspirated or whirling psychrometer. The "adjusted" depression procedure cannot, however, be applied to a table for obtaining the relative humidity from aircraft observations. When this is required it is necessary to determine the dew point first and then refer to a second table in which the relative humidity is tabulated for known values of dry bulb and dew point.

For purposes of upper air analysis it is important that aircraft observations should be readily comparable with observations from radio-sondes. Also, it is important that the data provided by aircraft on the low-level legs of meteorological reconnaissance flights should be readily comparable with surface observations from ships and shore stations. In the new Washington codes, humidity is reported in the form of dew point in all these cases. It has therefore been decided that the revised edition of aircraft humidity tables should be in the form of a dew-point table, with wet bulb and depression of wet bulb as arguments, with a subsidiary table for obtaining the "adjusted" depression for any value of pressure down to 400 mb. These tables are printed on the obverse side of a card (Form 2628, revised 1949). On the reverse side of the card is a table reproduced from Part III of the "Handbook of weather messages, codes and specifications" from which dew point is obtained from readings of dry bulb and relative humidity. This table is primarily intended for use at radio-sonde stations, but it can equally well be used, in combination with the table on the obverse, for calculating the relative humidity from aircraft observations.

The substitution of wet bulb for dry bulb as the primary argument in setting out a hygrometric table may be somewhat repugnant to computers used to the older form of table. The widespread use of the humidity slide-rule has, however, I venture to think, prepared the minds of many meteorologists to accept the thesis that the new procedure is really the more natural and logical, having regard to the shape of Regnault's formula.

THE HOLLERITH CARD SYSTEM APPLIED TO UPPER AIR DATA

By D. DEWAR, B.Sc.

The Hollerith card system was adopted for upper air work by the British Meteorological Office in January 1948 to deal with the large and increasing amount of data being obtained from upper air observing stations. Observations are punched on the cards at the stations and sent to a central office at the end of each month where only a small staff is required for the administrative side of the system. When sufficient data have been collected this staff will be able, using machine sorting and tabulating methods, to produce all the statistical information available about upper air conditions over the British Isles and along many of the Empire air routes.

Cards for a few remote stations such as the Falkland Islands and the ocean weather ships are punched at the London Headquarters from the data sent in by the stations. Altogether, just over 130,000 cards a year are being collected so an efficient filing and indexing system is essential.

A Hollerith card is a thin piece of cardboard, $7\frac{1}{2}$ in. $\times$ $3\frac{1}{4}$ in. with 80 columns of numerals running from 0 to 9 in each column. Headings for the columns are printed to meet the requirements of the user of the card. Upper air cards have headings for date, time, place, units, etc., at the beginning of each card, followed by headings giving for different pressure levels the observations for those levels: wind direction and speed on wind cards; temperature, humidity, height of the pressure level and supplementary information on temperature cards. There are two cards for upper winds and three for upper air temperature and humidity. Figs. 1 and 2 show the cards on a reduced scale.

Observations are recorded on the cards by punching small rectangular holes at the appropriate place on the card using a Hollerith punching machine. This has a set of keys numbered 0 to 9 and two "overpunch" keys, marked "X" and "Y" respectively; the base plate of the machine has a scale numbered 0 to 80 along which moves a pointer attached to a sliding card carriage, indicating the column in which the hole will be punched. Suppose a temperature of -15°F . at the 500-mb. level (about 20,000 ft.) is to be recorded. To overcome the difficulty of minus temperatures 200 is added to all temperatures so this 500-mb. temperature would be punched as 185. The carriage is set so that the pointer is against the appropriate column number and the 1, 8, 5 keys depressed in turn. The carriage holding the card moves automatically to bring the next column into position after a key has been depressed. The overpunch keys are used to save a column being provided for a figure which would only be required occasionally. They punch holes one or two lines, respectively, above the row of numerals in a column. Relative humidity, for example, is usually less than 100 per cent.; when a reading of 100 per cent. occurs 00 is punched and also an overpunch above the first 0 to show that a 1 precedes the 00.

After some practice an assistant can punch the upper air cards at the rate of about 30 an hour. Types of cards used for recording commercial information usually have a simpler lay-out than the upper air cards and do not use all the 80 columns; a trained operator can punch these cards at the rate of about 150 cards an hour.

As errors are unlikely to be detected when the cards are being sorted and analysed mechanically the cards must be meticulously checked after punching either by "reading back" or using a "verifying punch". Verifying punches are expensive and not at present used in meteorological offices. The cards are also tested for mechanical punching defects by placing them on a special gauge. Since any error necessitates punching a completely new card the greatest care has to be taken to ensure accuracy at the first attempt. The machines which sort and tabulate the cards necessarily work to very fine limits so that cards only slightly warped are liable to cause a jam. Great care has therefore to be exercised in storing and despatching cards to ensure they are not damaged.

The extraction of statistical data from the cards can best be illustrated by an example. Suppose the average relative humidity, extreme values and frequencies of 10 per cent. ranges are required for a certain station at the 500-mb. level for the midday ascent. There will be roughly 2,000 cards to be examined. The various sorting and tabulating machines operate on the same basic principle; the appropriate columns of a card are "scanned" by minute wire brushes

MEAN PARTIAL THICKNESSES AT LARKHILL IN DIFFERENT AIR MASSES DURING WINTER

BY R. MURRAY, M.A.

In his paper "The temperature characteristics of different classes of air over the British Isles in winter"*, J. E. Belasco has tabulated the mean values of temperature at various heights. The purpose of this article is to draw attention to the probable mean values of the partial thicknesses 1000-700 mb. and 700-500 mb. relevant to Larkhill in winter (winter refers to the months December, January, February) in Belasco's air-mass classification. Belasco's work is then in a form more suitable for useful application to modern upper air analysis technique.

Belasco's air-mass classification.—The two fundamental air masses—polar and tropical—are subdivided into 12 types on the basis of trajectory and curvature of the surface currents (as given by the sea-level pressure chart).

Main type	Sub-type	Criteria
Tropical	T ₁	Origin, Atlantic south of 40°N.; non-anticyclonic curvature.
	T ₂	Origin, Atlantic south of 40°N.; anticyclonic curvature.
	T ₃	Origin, Mediterranean or north Africa south of 40°N.
Polar	P ₁	Direct polar outbreak from north; non-anticyclonic curvature.
	P ₂	Direct polar outbreak from north; anticyclonic curvature.
	P ₃	Approaching from north-west; non-anticyclonic curvature.
	P ₄	Approaching from north-west; anticyclonic curvature.
	P ₅	Approaching from west; non-anticyclonic curvature.
	P ₆	Approaching from west; anticyclonic curvature.
	P ₇	Approaching from south-west, after travelling south-east towards Azores.
	A ₁	Siberian air from east; non-anticyclonic curvature.
	A ₂	Siberian air from east; anticyclonic curvature.

Currents A₁, A₂ and T₃ travel mainly over land tracks.

Belasco's mean temperatures

(a) British Isles

Height	Air-mass types											
	T ₁	T ₂	T ₃	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	A ₁	A ₂
ft.	<i>degrees Fahrenheit</i>											
20,000	-9.0	-5.3	-10.8	-44.7	-31.2	-41.6	-32.5	-34.3	-24.0	-24.4	-46.7	-26.8
15,000	9.8	14.1	8.8	-22.7	-10.9	-19.1	-12.9	-12.6	-3.9	-2.1	-26.6	-6.9
10,000	25.6	30.5	25.9	-2.5	5.6	1.5	4.7	7.6	14.9	16.3	-7.6	9.5
5,000	39.0	42.9	39.0	16.8	18.2	21.2	21.4	26.4	28.1	32.0	11.0	21.8
3,000	43.7	45.1	39.5	24.5	24.9	29.3	28.6	34.1	33.6	38.3	18.5	25.2
2,000	45.5	45.4	37.9	28.4	28.7	32.7	32.3	37.7	37.7	41.8	21.5	27.7
1,000	46.9	44.8	34.3	31.2	31.3	35.5	34.0	40.0	38.3	44.6	26.0	30.4
Surface†	50.5	47.3	39.3	33.9	33.9	39.7	36.9	43.5	41.0	47.1	29.9	33.9

†Mean surface temperatures at Kew.

*Quart. J. R. met. Soc., London, 71, 1945, p. 351.

(b) The mean values of temperature at upper levels of tropical and polar air in the Azores and Icelandic regions respectively are as follows :—

	Height (ft.)						
	20,000	15,000	10,000	5,000	3,000	2,000	1,000
T _A	−1·8	17·6	34·1	45·1	49·4	52·4	56·9
P _I	−56·9	−35·8	−15·6	4·6	14·7	19·2	23·9

T_A is northward-moving tropical current in Azores region.
P_I is southward-moving polar current in Iceland region.

Probable mean values of partial thicknesses at Larkhill.—Using Belasco’s mean upper air temperatures for the British Isles and his mean surface temperatures at Kew together with the winter mean sea level pressure at Larkhill, the pressures corresponding to 1,000, 2,000, 3,000, 5,000, 10,000, 15,000 and 20,000 ft. in the different air masses were calculated. The various ascent curves were then plotted on tephigrams, thus enabling the partial thicknesses to be worked out. It is thought that values calculated in this way represent to a fairly high degree of approximation the mean partial thicknesses (in feet) at Larkhill in winter in the different classes of air. These values are tabulated below, together with estimates of the mean temperatures at 700 mb. (θ_7) and 500 mb. (θ_5).

	T ₁	T ₂	T ₃	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	A ₁	A ₂
1000–700-mb. thickness (ft.)	9,460	9,520	9,420	9,070	9,110	9,140	9,160	9,250	9,280	9,350	8,970	9,150
θ_7 (°F.)	26	31	26	−1	7	3	6	9	15	16	−5	10
700–500-mb. thickness (ft.)	8,480	8,550	8,470	7,960	8,130	8,020	8,120	8,130	8,270	8,270	7,900	8,230
θ_5 (°F.)	−3	1	−4	−33	−22	−30	−23	−24	−16	−16	−36	−18

It should be noted that Belasco’s mean surface temperatures for Kew have been taken as applicable to Larkhill in constructing the upper air ascents. This appears justified because (i) Larkhill is near to Kew, (ii) mean winter surface temperature at Larkhill differs by only about 1°F. from the Kew value and (iii) even a difference of several degrees between the Larkhill and Kew temperatures makes a negligible difference to the calculated partial thicknesses. As regards the surface pressure the mean winter value at Larkhill has been taken, though more accurate results would be obtained if the mean surface pressures in the different air masses were known. This uncertainty is unlikely to introduce an error of more than about 50 ft. in the values of the mean partial thicknesses tabulated above (the error is positive or negative according as the surface pressures are respectively less or greater than the mean winter surface pressure).

Mean partial thicknesses at main source regions.—Using Belasco’s data the following values of partial thicknesses and 700-mb. and 500-mb. temperatures have been calculated.

	1000–700-mb. thickness		700–500-mb. thickness	
	θ_7		θ_5	
	ft.	°F.	ft.	°F.
T _A	9,600	34	8,600	3
P _I	8,900	−11	7,780	−43

In the calculation of these values the surface temperatures at the Azores and Iceland have been estimated by extrapolation from Belasco's mean upper air data; for surface pressure the mean winter values for Lagens (Azores) and Reykjavik (Iceland) have been adopted.

Practical application.—Means of meteorological elements do not generally constitute a firm basis for forecasting, but the calculated mean partial thicknesses in different air masses should assist the upper air forecaster at least by preventing improbable forecasts of partial thicknesses over southern England during the winter months. It might even be that more positive help can be given. For instance, the partial thicknesses may be known at Lagens in the tropical air of a warm-sector depression which is moving towards the British Isles with a warm front likely to bring the tropical air over southern England. As a first approximation, the upper air analyst may assume that the Larkhill partial thicknesses in the warm air will be the appropriate mean values given above. If the known Lagens thicknesses differ much from the mean values given above, a second approximation can be made by adjusting the Larkhill means by a proportionate amount. A further adjustment can be made if the Larkhill surface pressure in the warm air is likely to be greatly different from the mean winter value (about 1015 mb.). The estimate thus made can then be compared with the forecast based on the advectional-empirical methods at present in use; if the values differ substantially some compromise may be indicated.

A note of warning must be sounded. Belasco's air-mass classification is reasonable and practical, but no classification can ever be entirely satisfactory: there must always be border-line cases or cases defying classification by virtue of cutting across whatever subdivision is adopted. Even so, a critical analysis will often enable the forecaster to make some allowance for this difficulty, say, by taking intermediate values between the means calculated in this note using Belasco's air-mass classification and data.

METEOROLOGICAL OFFICE DISCUSSION

The measurement of humidity

The discussion on March 28 took the form of a symposium on the measurement of atmospheric humidity and was opened by Dr. D. N. Harrison and Mr. J. R. Bibby.

Dr. Harrison began by pointing out the large range of variation of water-vapour pressure in the atmosphere. Between saturation at tropical surface temperatures and the very low relative humidities of the stratosphere, the ratio is about $10^7 : 1$.

The following quantities are commonly used to specify the humidity, or are given by the readings of instruments:—

1. (a) Vapour pressure, e
(b) Dew (or frost) point, T_d
2. Vapour concentration (density), d_v
3. Relative humidity, U .

Adding to these

4. Temperature, T

and remembering that the dew or frost point is a function of the vapour pressure, so that these may be counted as one, we have four quantities, between which two physical relations exist ($d_v/U = f(T)$ and $d_v T/e = \text{constant}$). Thus if any two are known the other two can be calculated. We always measure temperature, but humidity instruments measure various different things, and it is a matter of importance to the instrument designer to know what accuracy is required at different parts of the scale: for instance, do we want to know the relative humidity with the same "probable error" at high and low humidities and at high and low temperatures? or do we want the vapour concentration with a certain absolute error, or a certain percentage error?

Some of the chief methods of measuring humidity are shown in the table (after Middleton*) roughly in order of the time required to make an observation.

Method	Quantity measured	Remarks
A. Slow		
1. Total absorption (gravimetric, etc.)	Vapour concentration or pressure	Absolute method. The most accurate.
B. Intermediate (equilibrium, involving lag)		
2. Psychrometric	$e_{Tw} - e$	Inaccurate at low temperatures.
3. Absorption		
a. Change of dimensions (hair, gold-beaters' skin, etc.)	Relative humidity	Slow response at low temperatures; hysteresis.
b. Electrical resistance (lithium chloride, zinc chloride, ceramics)	Relative humidity	Capable of faster response than 3a. Temperature correction.
c. Film thickness by interference	Relative humidity	Fast response. Independent of temperature.
d. Dew-point recorder	Vapour pressure	Uses lithium-chloride solution.
4. Diffusion	Vapour pressure	
5. Condensation	Dew (frost) point	Suitable for low temperatures. Absolute method.
6. Thermal conductivity	Vapour concentration	
C. Miscellaneous		
7. Aircraft trails	Relative humidity	
8. Temperature rise on absorption of water vapour by cotton	Vapour pressure?	
D. Instantaneous		
9. Infra-red absorption	Total water content along path	Knowledge of absorption coefficients required.
10. Dielectric constant } Refractive index }	Vapour concentration	

Notes—Method 2 measures the difference between saturation pressure at wet-bulb temperature and existing vapour pressure.

Methods 3a, 3b, 3c require calibration.

Methods 2, 3a and 3b have been used in radio-sondes.

The first method is really an analysis. It consists in absorbing all the water vapour in a given sample of air and weighing it or measuring the change of pressure. It is an absolute method (that is, it does not depend on the properties of any substance or on the calibration of an instrument) and is very accurate, but too slow for meteorological purposes.

*MIDDLETON, W. E. K.; Meteorological instruments. Toronto, 2nd edn., 1943.

Next we have a group of methods (Nos. 2-6) in which a state of equilibrium has to be established and some factor in the equilibrium condition is a measure of the humidity. All these involve more or less lag, since the equilibrium takes a finite time to establish itself.

In the psychrometric method the equilibrium is thermodynamic.

Methods 3 *a*, *b* and *c* depend on the change in some property of a substance which absorbs moisture, and therefore involve calibration. The first group, consisting of hair, gold-beaters' skin and some other substances, responds by a change of dimensions. The primary controlling factor is relative humidity (below freezing point, the relative humidity with respect to water) but hair has also a temperature coefficient. Glückauf found that the calibration of gold-beaters' skin was independent of temperature over a wide range. These substances, being semi-crystalline in structure, suffer from serious hysteresis after exposure to low humidities, owing to internal strains set up by drying.

Group 3*b* consists of substances which respond by a change of electrical resistance. Instruments using lithium-chloride solution are now well known; they have a large temperature coefficient, and also polarise if direct current is used, but can be made faster in response than 3*a*. There are also ceramic substances, such as kaolin, whose resistance changes with humidity; these are not yet well understood.

The thickness of a hygroscopic film, of the order of one wave-length of light, has been measured by an interference method 3*c*, and this has been shown to provide a very rapid measurement of relative humidity, independent of temperature.

Another application of lithium chloride is in the dew-point recorder, which will be described later.

The diffusion hygrometer depends in principle on the difference between the rate of diffusion of air and of water vapour through a porous membrane.

The dew- or frost-point method is an important one because of its accuracy at low temperatures, because it is an absolute method, and because a sample of air can be subjected to variations of temperature without change in its dew (frost) point, provided that moisture is not added to or taken from it. The frost-point hygrometer will be described later.

The thermal conductivity of air depends on the amount of moisture present, and an instrument based on this principle has found industrial applications.

A theory has been worked out (No. 7) according to which the length and diameter of aircraft condensation trails could be used to give a measure of relative humidity, but has not been tried in practice.

It has been found that, if a mass of dry cotton be exposed to a humid atmosphere, its temperature rises as it absorbs moisture, probably owing to the release of the latent heat of vaporization. An instrument which works on this principle has been described (No. 8), but it appears to be little more than a curiosity.

All the methods described so far involve alteration of the composition of the air sampled. The remaining methods leave the sample unchanged and are also instantaneous.

Water vapour has strong absorption bands in the infra-red, and these may be used to measure the vapour concentration by observation of the absorption over a measured distance (No. 9). A knowledge of the absorption coefficients is required, and the situation is complicated by the fact that they depend on both the temperature and the total pressure. No doubt laboratory experiments will elucidate these matters.

Lastly, the dielectric constant and refractive index of air depend on the amount of moisture present, and are capable of measurement: for instance, by the variation in frequency of a resonant cavity containing the air.

Methods suitable for use in a radio-sonde were next considered. The requirements are:—

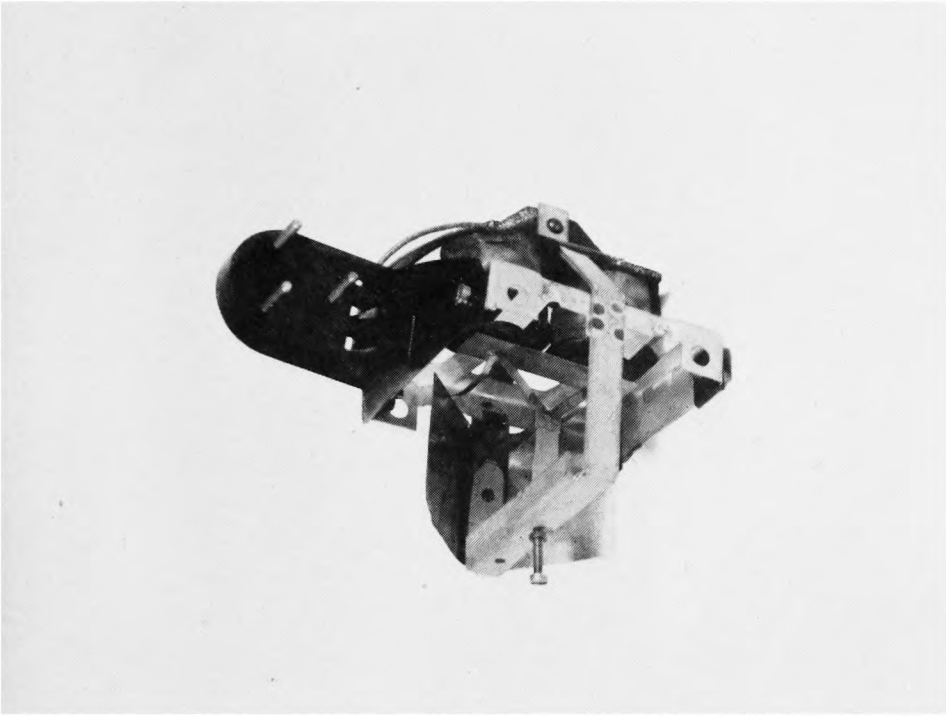
- (i) The instrument must give a response of a type which can be telemetered,
- (ii) It must be light, small in bulk, and cheap,
- (iii) The response must be as rapid as possible, with a minimum of hysteresis, and the calibration stable.

Although gold-beaters' skin is the best of the substances in group 3*a*, the electrical-resistance types 3*b* offer a better prospect for future development, in respect of speed of response and absence of hysteresis. It is unfortunate that method 3*c* presents great difficulties in telemetering.

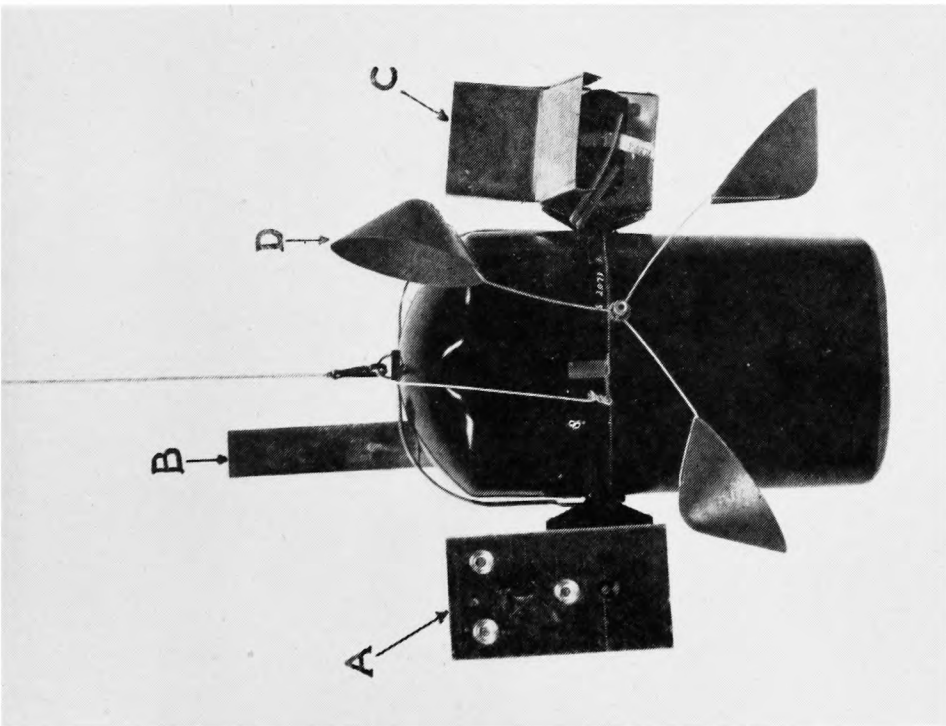
Mr. J. R. Bibby then described a number of hygrometers in greater detail, the first one being the Dobson-Brewer frost-point hygrometer. This instrument is noteworthy as having given the first accurate measurements of humidity in the high atmosphere and having led to the discovery (by Brewer in 1943) of the extreme dryness of the stratosphere. The instrument depends upon the deposition of frost from a jet of air upon the cooled surface of an aluminium thimble. In early models the observer controls the cooling so as to maintain a steady film, a process needing considerable practice. Later developments have made this easier, a photo-electric cell being used to detect the ice deposit. In the latest model, now under development, automatic control of the thimble temperature by the deposit itself ensures that the thimble is maintained continuously at the frost-point temperature. It was pointed out that this type of instrument is almost unrivalled among hygrometers in combining simplicity of theory with stability of calibration.

Mr. Bibby went on to describe two hygrometers which depend on the vapour pressure of a solution being lower than that of pure water. Lithium chloride is the usual solute. In the Gregory humidimeter a strip of cloth soaked in solution is wound on a metal frame to enable its electrical conductivity to be measured. Changes in relative humidity cause changes in the concentration of the solution and hence in its conductivity. A simple alternating-current circuit enables relative humidity to be indicated directly on a dial, or on a remote recording galvanometer. The scale is very non-linear, but elements can be made to have maximum sensitivity in any desired part of the range. This is an advantage for many industrial users, but a drawback for meteorological work. Other disadvantages are the need for temperature corrections, and the risk of lithium chloride being washed away by wet fog.

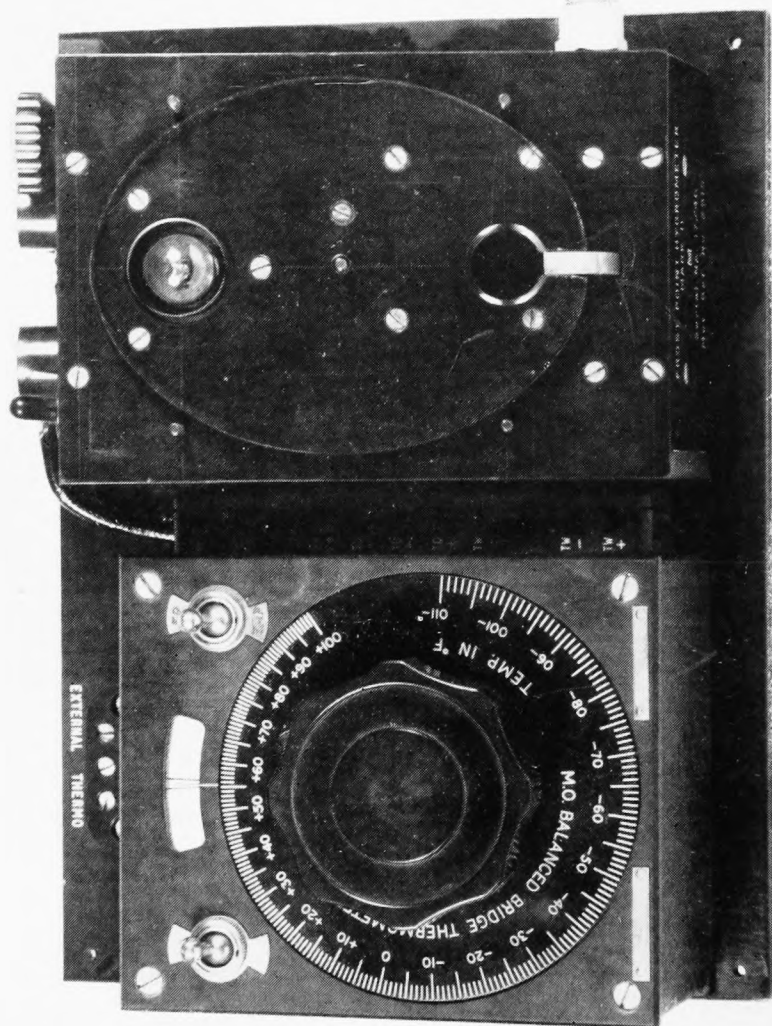
An American hygrometer using a somewhat similar element was then described. A higher potential (about 25 volts A.C.) is applied, and conduction



HUMIDITY ELEMENT OF THE RADIO-SONDE
The gold-beater's skin can be seen stretched out in line with the screw.

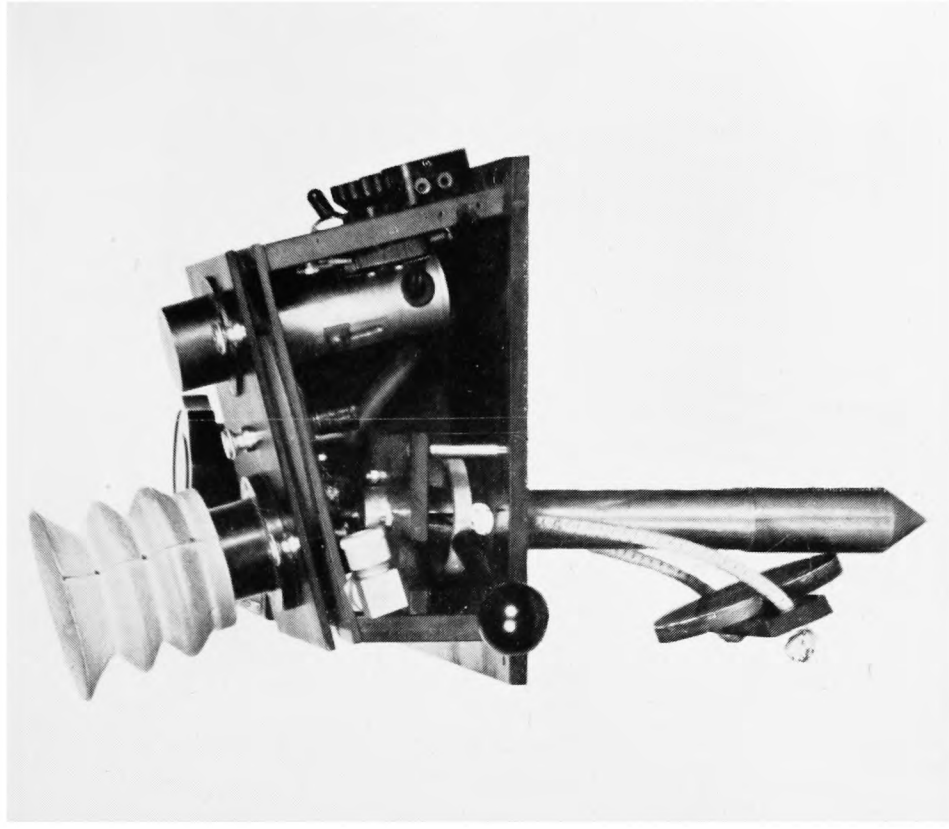
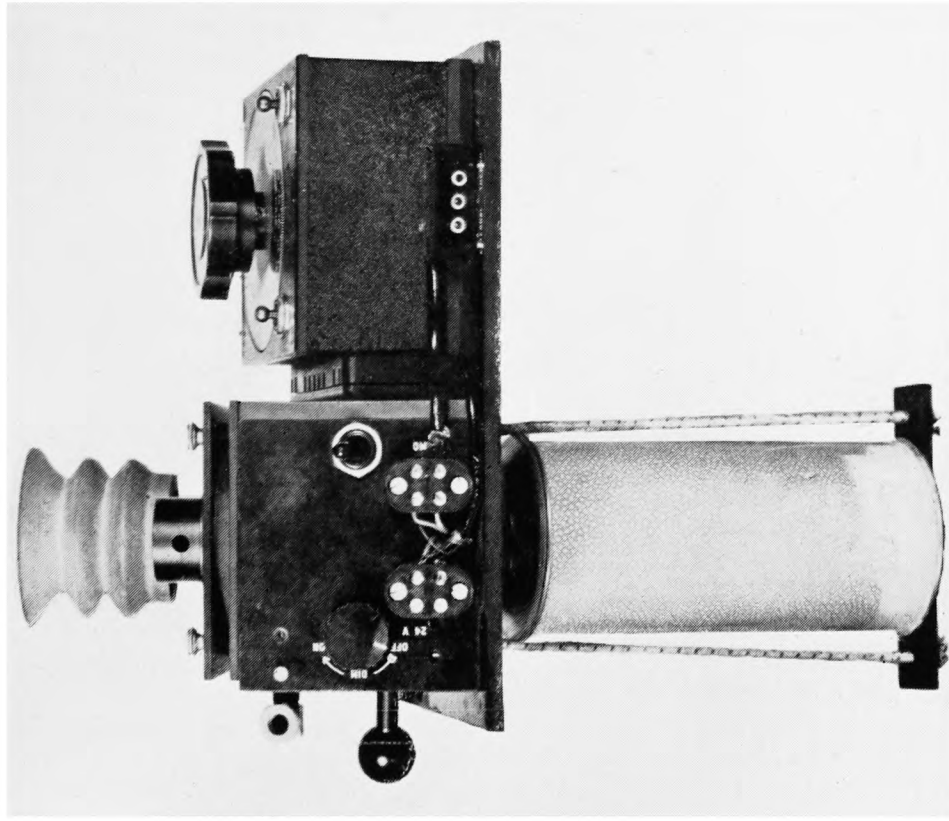


METEOROLOGICAL OFFICE RADIO-SONDE, MK. II
A = pressure element, B = temperature element, C = humidity element, D = windmill for the switching mechanism.



DOBSON-BREWER FROST-POINT HYGROMETER

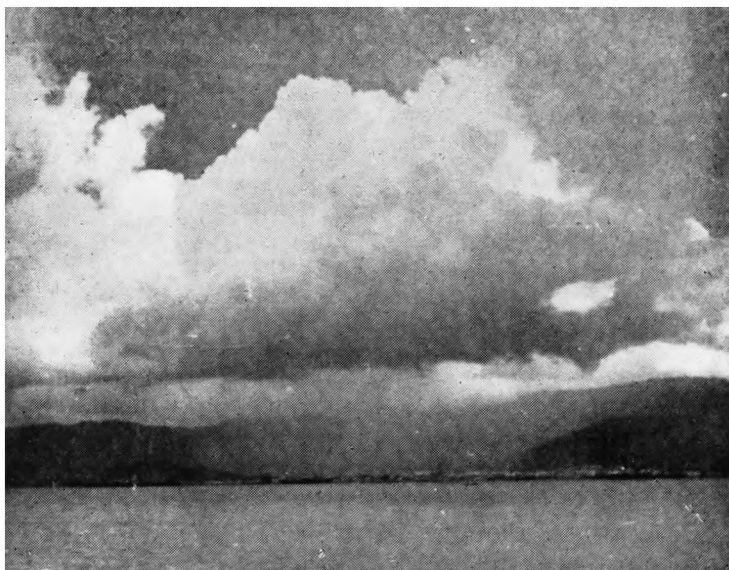
The cover has been removed showing the elliptical mirror which concentrates the light from the small bulb at one focus on to the black surface of the thimble at the other focus. The balanced-bridge thermometer is on the left. (See p. 172)



DOBSON-BREWER FROST-POINT HYGROMETER

The left-hand photograph shows the complete instrument, the right-hand one the instrument from the side showing the pump containing the cooling fluid.

To face page 173]



HEAVY PRECIPITATION FROM A CUMULIFORM CLOUD OVER
GEORGETOWN, MALAYA

(see p. 178)



PUMP AND THIMBLE OF THE DOBSON-BREWER HYGROMETER

The visible leads are connected to the two ends of the platinum-wire resistance by means of which the temperature of the thimble is measured.

through the lithium-chloride film causes its temperature to rise. This goes on until evaporation reduces the current flowing, and equilibrium is reached at such a temperature that the vapour pressure of the saturated solution equals the ambient vapour pressure. There is thus a constant relationship between the equilibrium temperature of the element and the vapour pressure (and hence the dew point) of the air. The element is wound on the bulb of a mercury-in-steel thermograph, and the recorder shows the dew point directly if a suitable scale is printed on the chart.

Mr. A. G. Matthewman, continuing the discussion, spoke from the point of view of the synoptic meteorologist. Psychrometric observations at the surface (from a Stevenson screen) and in the lower levels (from a captive balloon) are valuable, and radio-sonde readings are used up to the 700-mb. level, but in all cases there is an element of doubt how far a single observation or ascent is representative. Radio-sonde data are at present used in the form of dew points, but *Mr. Matthewman* considered that the wet-bulb potential temperature might prove preferable. Investigation was needed to discover whether increased accuracy of humidity measurement would be helpful or futile, having regard to the scale of the real variations in the atmosphere. For the forecasting of small-scale phenomena, *e.g.* cloud formation, the present standard of accuracy is probably not good enough. He thought that a device by which a radio-sonde could report the presence of cloud particles would be valuable.

Dr. G. D. Robinson expressed doubt whether psychrometric readings from a screen were satisfactory to the forecaster, and said he would like to have vapour concentration accurate within 1 per cent. On the basis of comparisons with radiation measurements he considered that radio-sonde humidity values were better than is often supposed.

Dr. F. J. Scrase pointed out that one of the advantages of the frost-point hygrometer was that the sensing element—the thimble—possesses a durable surface not easily damaged by a high rate of ventilation, an advantage not shared by hair, gold-beaters' skin or lithium-chloride film. He also suggested that it might be possible to make an instrument for measuring humidity on the cloud-chamber principle, in which condensation takes place in the air.

Dr. J. M. Stagg pointed out that in the resolutions of the I.M.O. Conference, 1947, relative humidity is defined in terms of mixing ratios instead of vapour pressures, and asked to which of these quantities substances such as gold-beaters' skin actually responded.

Mr. D. D. Clark described some of the difficulties of the frost-point hygrometer. At temperatures between freezing point and -15°C . it is difficult to be sure whether it is dew or frost that is formed, and, in this respect, each thimble surface has its own individuality which may change with use. At about -80°C . the deposit is formed as amorphous ice, which cannot be detected, owing to its glassy surface. *Mr. Clark* suggested that at low atmospheric pressures the accuracy of the psychrometric method might improve, owing to the factor p in the psychrometric equation.

Cdr. C. E. N. Frankcom described the difficulties of measuring humidity at sea.

Mr. C. J. M. Aanensen wanted an instrument suitable for use on fast aircraft.

Mr. O. M. Ashford thought it should be possible to state the accuracy required in synoptic meteorology. He stressed the importance of adequate ventilation

of psychrometers, saying that some clockwork Assmann psychrometers were defective in this respect. The new hand-operated psychrometer had been specially designed for use on board ship. He referred to the improvement in the performance of hairs treated by the Frankenberger process. With regard to Mr. Clark's suggestion, Mr. Ashford pointed out that at low pressures the lag of the psychrometer would become very large.

Mr. A. J. Drummond stressed the fact that serious errors could arise in the psychrometric method through the use of an incorrect constant, and said that satisfactory results had been obtained below freezing point by the use of saturated solutions of various salts.

Mr. P. M. Shaw described comparisons which he had made between psychrometric readings from a screen, an Assmann and a hand-operated psychrometer, and suggested that the psychrometric tables used for screen readings on land were not appropriate for a Bilham screen on board ship, where the ventilation is greater.

Mr. W. H. Hogg, discussing the use of the hand-operated psychrometer in microclimatology, said that the difficulty was to obtain air from the exact level desired without disturbance by the observer or contamination by air which had passed through the instrument.

Mr. Hickman (National Physical Laboratory) said, in reply to Mr. Hogg, that the best method would be to use long tubes to sample the air. He pointed out that the design of the Assmann psychrometer is faulty: the air flow should be at right angles to the thermometer bulbs. He suggested a psychrometer employing thermo-couples.

Dr. Harrison and *Mr. Bibby* replied briefly to the discussion. With reference to Dr. Scrase's suggestion, Dr. Harrison said he thought there would be difficulty in knowing the precise degree of supersaturation at which condensation took place. In reply to Dr. Stagg's question, the difference between the relative humidity defined in the two ways was so small that the matter could not be settled by experiment. Mr. Bibby thought that what the gold-beaters' skin responded to was the relative humidity as defined by the vapour pressure rather than by the mixing ratio.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

PROFESSIONAL NOTES

No. 96—Cooling of air by rain as a factor in convection. By J. S. Sawyer, M.A.

The rain produced during convectional storms cools the air through which it falls, and the cooled air descends as its density is greater than that of the surrounding air. This is an important part of the process of convection. It may be responsible for the release of as much energy as is due to the buoyancy of upward currents; also the downward currents of cooled air may be deflected by hills and determine the later development and movement of a storm. Pressure may rise several millibars as the result of cooling of air by rain.

The most favourable conditions for the development of the phenomena occur in tropical regions on the borders of continents; similar but less intense effects are produced in temperate latitudes.

No. 97—Some correlation coefficients between certain upper air data. By Sir Gilbert T. Walker, C.S.I., F.R.S.

The author gives correlation coefficients and regression equations between ozone content, pressure at 0, 5, and 7 Km., temperature at 1, 5, and 7 Km. and the height of the tropopause. Some of the data over southern England are for the period January to September 1940 and some for June to October 1941.

The first aim was to determine if ozone was more closely related to subsequent pressure at 5 Km. and temperature at 7 Km. than with those elements for the same or previous days. This was found not to be the case.

The correlation coefficients found are in general agreement with those found by others. An attempt at a physical explanation of the coefficients is made based on a description by B. and E. Haurwitz* of pressure and temperature variations in cyclones. The temperature changes associated with the passage of isallobaric highs and lows as described in the Haurwitz paper agree well with the correlation coefficients except near the ground where they are in the opposite sense. The change near the ground is ascribed to the lack of recently formed cyclones over England.

One of the Haurwitz diagrams suggests it should be possible to predict the height of the tropopause from the surface pressure. The coefficients are found not to encourage this idea, and all that can be said is that when pressure changes are not too rapid the changes in surface pressure precede those of the height of the tropopause, but when pressure drops and recovers rapidly in 24 hours there is no suggestion of precedence in surface pressure.

The following publication will be issued shortly:—

GEOPHYSICAL MEMOIRS

No. 82—Weather forecasting in tropical regions. By A. G. Forsdyke, Ph.D., D.I.C.

This memoir consists mainly of a general commentary on the problem of weather forecasting in the tropics as it appeared in the later years of the second World War. It is based on the author's experience with the meteorological service in east Africa and the western Indian Ocean augmented for war purposes, together with the numerous notes and reports many of them unpublished, prepared by personnel of the meteorological services operating in tropical regions.

An introductory section outlines the uses made of weather forecasts in tropical countries. Then follow sections dealing with three main problems of tropical synoptic meteorology. First, the relation between wind and pressure distribution is considered from the point of view of modifications of the geostrophic-wind equation and other pressure-wind relations required in low latitudes. The special significance of convergence in the horizontal wind field is emphasised and a technique suggested for its calculation. Next follows a brief discussion of upper air temperature and humidity and convectional phenomena. A third section deals with the general principles of frontal analysis in the tropics having regard to the theoretical background as well as to forecasting and flying experience.

The memoir concludes with a list of problems for investigation suggested by the studies undertaken for its preparation.

*HAURWITZ, B. and HAURWITZ, E.; Pressure and temperature variations in the free atmosphere over Boston. *Harvard met. Studies, Cambridge, Mass.* No. 3, 1939.

METEOROLOGICAL RESEARCH COMMITTEE

At the 57th meeting of the Meteorological Research Committee, held on March 23, the annual reports from the sub-committees were received and the revised programme of research for the forthcoming twelve months was approved.

Four members of the Committee were nominated to serve on a Gust Research Panel, which has been instituted, jointly with the Aeronautical Research Council, under the chairmanship of Sir Geoffrey Taylor.

ROYAL METEOROLOGICAL SOCIETY

The meeting of the Society held on March 16, 1949, with Mr. E. Gold, Vice-President, in the Chair, took the form of a discussion on agricultural meteorology. The discussion was opened by Dr. H. L. Penman and Dr. L. Broadbent of Rothamsted and by Mr. R. W. Gloyne of the Meteorological Office.

Dr. Penman dealt first with the general requirements of agriculturists for weather forecasts. These were forecasts for a year ahead for long-term crop planting strategy, for about 14 days for mobilising equipment to deal with plant diseases, and short-term ones for such matters as protection against frost. He then went on to discuss, as his main topic, the effects of incoming radiation on the evaporation of water from the soil and the transpiration of water from plants. He stated that in the long run around 90 per cent. of the energy of the incoming radiation was used up in providing energy for evaporation from soil and plants. Experiments were described showing that transpiration from plants amounted to about 75 per cent. of evaporation from a free-water surface under similar meteorological conditions. Finally, he described an experiment in controlled irrigation carried out in Surrey in 1948, in which the crops grown in areas irrigated according to instructions based on rainfall and temperature measured over a period, were compared with those on areas irrigated by the farmer in the usual way.

Dr. Broadbent described the effects of weather on potatoes in great detail. He dealt first with the effects of spring weather on the sowing of the seed potatoes and of summer weather on the development of the tuber. Cold weather in spring, delaying planting by a day, reduces the crop by about five per cent., while hot dry weather in late summer is very deleterious. The effects of weather on potatoes in the warmer parts of the British Isles are, however, mainly concerned with the transmission of virus diseases by aphides. These insects can only fly in winds of under 2 m.p.h. and they develop more quickly in hot weather. Dr. Broadbent gave much detailed information on this subject.

Mr. Gloyne, who had little time after other speakers had finished, dealt with the need for accurate weather forecasts for disseminating insecticides in dust or spray form, and with the use of climatological data in agricultural planning. On the first topic he pointed out that the distribution of the insecticides is much affected by wind, and that the dust needs something to stick to on the leaf surface, so that dew forecasts may be necessary. Applied climatology was of value in deciding whether a particular agricultural method could be used. Thus, haymaking by swath-curing needs three successive dry days, and the question arises as to how often such favourable sequences can be expected in any part of the country.

The general discussion which followed was a lively one. Among the points raised were the desirability for a forecast service for farmers as good as that now provided for aviators, the modification of general area forecasts to individual farms *e.g.* in connexion with frost, meteorological conditions for the growth of cotton in the Sudan, and the need for a detailed micro-climatological survey of the country to assist in deciding what areas should be used for new towns and what devoted to agriculture.

ROYAL ASTRONOMICAL SOCIETY

A meeting was held on January 28, 1949, to discuss river-flow survey and records, Sir Roger Hetherington being in the chair.

Mr. H. J. F. Gourley opened the discussion with a general account of the use of water for supply, both from reservoirs in the upland regions and from the main river. In the absence of river-flow records, estimates of the potentialities of any area had had to be based in most cases on rainfall records, but with the passing of the Rivers Boards Act 1948 the Minister of Health is given powers to direct a River Board to measure the flow of any river, stream or inland water in the area, as well as to record the rainfall.

Dr. J. Glasspoole dealt with the effect of the meteorological factors of rainfall and evaporation on the run-off. Where records of both annual values of rainfall and run-off are available, the correlation coefficient is usually of the order of $+0.9$, but more records of run-off are necessary to define the variation of the loss (rainfall minus run-off) over the country. He thought that the greatest progress would be made by considering the whole hydrological cycle of rainfall, evaporation and run-off.

Capt. W. N. McClean gave an account of his own work in measuring the flow of Scottish rivers, especially in regard to the practical difficulties.

Mr. W. Allard, who had been concerned with publication of the *Surface Water Year Book of Great Britain* by the Ministry of Health and Scottish Office before the war, gave an account of what might be done as a result of the Rivers Board Act 1948 to define the flow, and enumerated some of the methods of expressing the results as set out in "Flood Estimation and Control" by B. D. Richards.

Mr. E. Gold referred to the accuracy which could be obtained by the scientific study of rainfall data and the importance of run-off records as a means of determining the evaporation. There were difficulties in measuring the evaporation directly because of the great variety of different types of surfaces involved. He also regarded as important the effect of the rain on different surfaces in changing the height of the stream. It is interesting to recall that Mr. E. Gold was Vice-Chairman of the British Association Research Committee which reported in 1933 on the Inland Water Survey in the British Isles.

Mr. R. V. Stock, Chief Engineer to the Thames Conservancy Board, referred to the long series of run-off records available since 1883 for the Thames Valley draining to Teddington, which had been summarised in various publications, and to proposals to construct two additional weirs for the measurement of the flow further up stream.

Further discussion dealt mainly with the accuracy of the measurement of river flow by various methods, details being given by Sir Claude Ingles.

LETTERS TO THE EDITOR

Formation of rain

The top photograph facing p. 173 is submitted in response to Mr. Best's letter published in your issue of October 1948. It was taken at Butterworth, Malaya, looking towards Penang Island, at 1335 on May 2, 1947, and shows a cumuliform cloud giving heavy precipitation over and behind Georgetown. While there is no instrumental evidence, there is good reason for thinking that this precipitation originated at temperatures above 0°C .

The height of the cloud top can be calculated from the estimated distance of the cloud and the size of the photographic image and can be shown not to exceed 12,000 ft. A freezing level below this is hardly compatible, in moist conditions, with the surface temperatures exceeding 80°F . which regularly occur in Malaya during the afternoon. Indeed, at that time of the year a freezing level of 15,000–17,000 ft. would usually be forecast.

There is no doubt that the rain falling on the town originated in the cloud in question as at that time there was in that direction no higher cloud formation in which it could have originated.

Other cumulus towers in the vicinity, giving precipitation of which traces appear in the upper part of the photograph, were much higher than the cloud here shown, and showed signs of ice formation in their upper parts.

J. M. CRADDOCK

January 17, 1949

Structure of a fast-moving cold front

On the morning of October 21, 1948, an aircraft of Trans-Canada Airlines flying across the Atlantic on the great circle from Goose Bay to London Airport, made an interesting report on a fast-moving cold front, encountered about 0600 G.M.T.

At this time a depression of depth 985 mb. was centred at 59°N . 37°W . moving east-north-east at 35 kt. A cold front extending southwards from the centre was moving eastwards at about 40 kt. The warm air ahead of the front was tropical air ; the cold air behind, polar air from the Canadian arctic.

Flying at 15,000 ft., on a track at right angles to the front, the pilot reported an increase of temperature from -24°C . to -11°C . at about 45°W . This change took place in 10 minutes, in clear air, and was accompanied by moderate turbulence. The aircraft continued in clear air for a further 150 miles. It then entered cloud with moderate to heavy icing, and these conditions persisted for another 100 miles.

This is an excellent illustration of the standard type of fast-moving cold front. Text-books state that the frontal cloud of fast-moving cold fronts rises vertically above the base of the front. They also state that if the component of wind velocity perpendicular to the front increases with height, then warm air will descend the frontal slope, and it follows that there will be clear air above the frontal surface. Both these features are clearly illustrated by the pilot's report, the temperature discontinuity and turbulence indicating the position of the frontal surface at 15,000 ft., and the cloud indicating the position of the surface front. The 500-mb. chart showed that the thermal wind between 1000 and

500 mb. was 70 kt. at an angle of 25° to the front ; this was equivalent to an increase in the wind component at right angles to the front of 30 kt. in 18,000 ft. Moreover the approximate slope of the front was somewhere between 1/50 and 1/90 which is in good agreement with the average figure generally quoted.

F. A. SHARP

S. E. VIRGO

London Airport, February 17, 1949

NOTES AND NEWS

Supply of meteorological information to power and transport authorities

The Meteorological Office has for many years provided weather forecasts and warnings to public utility companies. During the past eighteen months there has been a considerable increase in these arrangements and this note gives a brief survey of the more important of them as they stand at present.

British Electricity Authority.—Forecasts are supplied to the National Control Centre by the Central Forecast Office and to the seven local Grid Control Centres by the nearest Type I forecast office. The National Centre receives at 6 a.m. daily a forecast of the temperature and wind and weather expected between 4 p.m. and 6 p.m. over England and at 6 p.m. similar information relating to 8 a.m. next day. A synoptic chart of the weather at 0600 G.M.T. is also sent daily from Victory House to the National Centre. The local Grid Control Centres receive forecasts five times daily of the temperature weather and wind over the areas they control. The last one, at 8 p.m., refers to the anticipated weather for 8 to 9 a.m. next day, the remainder are forecasts for up to 5 hours. Further outlooks for 12 hours accompany the forecasts.

A meteorological officer is attached to the Headquarters of the Authority to investigate the meteorological problems associated with electricity distribution, and to interpret the forecasts to meet the authority's requirements.

Gas Companies.—Gas Companies receive warnings of weather, such as cold, fog, or snow, which leads to a heavy public demand for gas. Warnings are issued under thirteen heads such as "Onset of cold or hot weather within next day or two", "substantial fall or rise of temperature within next 24 hours", "severe night frost with day temperature above freezing point", "temperature expected to remain below freezing day and night", "snow expected in substantial amount", "prolonged cold or hot spell", "thick or dense fog to-morrow", etc. Warnings are prepared by the Central Forecast Office and, prefixed by the words GASCO WARNING, are broadcast by teleprinter. Each gas company is looked after by an allotted meteorological office which distributes the warnings as they are received.

Ministry of Fuel and Power.—During winter months forecasts of the anticipated temperature on Saturday and Sunday are supplied to Regional officers of the Ministry of Fuel and Power. The forecasts are compiled by the Central Forecast Office and distributed by local meteorological offices.

British Railways.—Railway operations are seriously affected by fog, snow, frost, glazed frost and gales. Fog affects railways if visibility falls below 200 yd., and fog-working arrangements, for which special staff have to be deployed, are

then necessary. Snow is most serious when drifted into deep banks but may clog points without being very deep. Frost affects points, water troughs etc., while glazed frost causes lack of adhesion, and clogs points. Both snow and glazed frost are particularly serious on electric railways as they form an insulating layer on the conductor rail.

Warnings of the onset of these phenomena are prepared by Type I stations and supplied to the railway control officers allocated to them. Close liaison is maintained between the railway controllers and their meteorological advisers. The railway authorities send reports of current weather on their tracks as necessary, and forecasters have visited sections of track known to be particularly subject to weather troubles. The railway authorities keep their meteorological advisers on their toes by sending them weekly returns of the value of the warnings.

Shipping.—Arrangements have been made for masters of merchant ships, ship-owners and these concerned in the movements of shipping or cargo to obtain local weather forecasts from the forecast centres nearest to the main ports in Great Britain. To each main port is allocated a forecast centre. News of the service has been promulgated in *Notices to Mariners* and through Port Meteorological Officers and Merchant Navy Agents.

Snow clearance.—To enable Local Authorities to mobilise the labour and equipment necessary to keep the main traffic routes clear of snow, warnings are issued to County Surveyors, City Surveyors, and the Divisional Road Engineers of the Ministry of Transport.

Warnings of snow, with special mention of drifting, are compiled at the Central Forecast Office, broadcast by teleprinter, and telephoned by local meteorological offices to the Surveyors, etc.

Royal Automobile Club.—Forecasts and reports are supplied in winter to the Royal Automobile Club Touring Department and to local offices of the club. The information consists of forecasts of coming weather with statements of reporting stations with visibility less than 500 yd., or at which snow or sleet is falling, or with glazed roads, or where more than 20 mm. of rain has fallen in twelve hours. The messages are sent twice daily, at 10 a.m. and 3 p.m.

OBITUARY

The Right Hon. Viscount Ullswater, G.C.B., one of the outstanding Speakers of the House of Commons, who died on March 27, aged 93, was much interested in rainfall recording. Since 1912 he had caused an annual return of the observations at Campsea Ashe, near Woodbridge, Suffolk, to be sent for use in compiling the annual volumes of *British Rainfall*.

NEWS IN BRIEF

The Meteorological Office football team beat Air Ministry Accounts by four goals to nil in the final of the Air Ministry Football Cup at Northolt on April 12, 1949. This is the eighth occasion on which the Meteorological Office team has won the competition, and the second time in three successive seasons.

The football team of the Central Forecasting Office, Dunstable, won the Dunstable Benevolent Hospital Charity Cup on April 28, 1949, when they beat Totternhoe by two goals to nil in the final.

REVIEWS

The behaviour of barometric pressure during and after solar particle invasions and solar ultraviolet invasions. By B. Duëll and G. Duell. *Smithson. misc. Coll.*, **110**, No. 8. 8vo. $9\frac{1}{2}$ in. $\times$ $6\frac{1}{4}$ in. pp. ii+34. Smithsonian Institution, Washington, D.C. 1948.

Investigations of the influence of solar activity on weather have hitherto been mainly confined to the variation of the solar constant and sunspot numbers, and their correlation more especially with long-period weather changes. It is well known that the results so far obtained in this field are disappointing, the correlation coefficients being small, and their implications uncertain.

In this paper an attempt is made to relate atmospheric pressure with certain solar phenomena, namely solar particle and ultra-violet invasions, which are observed through their terrestrial effects and give some indication of solar activity. Since, until recently, solar particle invasions had not been directly observed, variations of the earth's magnetism, with which they are closely associated, have been used instead. The investigation is limited to daily values of the correlated phenomena.

Since the solar phenomena are generated by eruptive processes in the sun, they select certain key days of especially high solar activity. In the investigation, sets of key days have been determined from records of magnetic disturbance over the period 1906-37. The mean anomaly of sea-level pressure for each of a number of stations in Europe is calculated separately for the key days and each of the few preceding and following days, and graphed against time (the "superposed-epoch" procedure). Only for the winter months of the years near sunspot minima are the curves in any way remarkable, but then they show striking similarities. Some three days after the key day, in a disturbed period, the pressure falls to a well defined minimum, while in a quiet period it rises to a maximum after a similar interval, the average difference between maximum and minimum amounting to about 3 mb.

These results are in themselves very interesting, but their significance seems to lie in the geographical distribution of the pressure anomalies. The anomaly reaches its greatest negative value over Europe simultaneously with its greatest maximum value in the Iceland region, so that the normal pressure difference between these areas is reduced by some 5 mb. and the mean circulation must be affected accordingly.

For the ultra-violet invasions the investigation covers only the period 1936-41, but the results apply to all months. They are presented in much the same way as for particle invasions, and are equally striking. For stations in Europe, sea-level pressure falls somewhat for one or two days after the key day, but reaches a pronounced maximum on about the third to fifth day. There is also some effect on the topography of the 500-mb. surface, which, on the day after key day appears to undergo a lowering of some 120 ft. over western Europe, while a rise of similar amount takes place in the Baltic area.

In so far as the particle and ultra-violet invasions may be predicted over the period of a few days between the appearance of the eruptive areas on the sun's limb and the time, depending on the solar revolution, when they may be expected to have terrestrial effects, these occurrences have a possible forecasting value. Moreover, the eruptions sometimes persist through a number of

solar revolutions. The effects on the weather, if any, have still to be worked out.

Numerous physical explanations of the effects are suggested, but none of them go beyond the stage of conjecture. Neither is any statistical test applied, so that it is not possible to judge the reality of the effects, but the evidence appears convincing.

Apart from its general interest the paper points a way to further investigations in the fields of atmospheric physics and statistical and synoptic meteorology.

A. G. FORSDYKE

Grundprobleme der Physik des Gewitters. By H. Wichmann. *Phys. Forsch.*, 1, Heft 1, 8vo. $8\frac{1}{4}$ in. $\times$ $5\frac{3}{4}$ in. pp. 118. Wolfenbütteler Verlagsanstalt, G.m.b.H., Wolfenbüttel und Hanover, 1948. Price : DM. 8.

The publishers noted in the title have instituted a new series of publications entitled *Physikalische Forschung* of which the small book under review forms the first number. The series is to provide a medium of publication for research papers too long for scientific journals and is edited by the well known physicist, Dr. Pascual Jordan. According to a list of future numbers six of the ten numbers in the first two volumes are to deal with geophysical subjects including the dynamics of cyclones and the theory of seismic waves. The first number is in paper covers. It is well printed with clear figures. There is no index. We wish every success to the new series.

The main object of this book seems to be to develop a theory of the production of thunderstorm electricity due to Lange, Findeisen and Wichmann which has not yet attracted much attention outside Germany. It was first published in a series of papers in the *Meteorologische Zeitschrift* in 1940 and 1943. The experimental basis of the theory is that an insulated conductor in a stream of air becomes positively charged when rime forms upon it, negatively charged when rime evaporates, and strongly positively charged when supercooled water droplets freeze upon it. In the first and third cases the small ice splinters torn away by the air stream carry a negative charge but what happens to the positive charge in the second case is obscure. These phenomena are ascribed by Lange to contact potential differences between the different phases of water. The main separation of charge in the cloud is then ascribed to gravitational separation of the small ice splinters and the heavy hailstones with assistance from the Wilson process which is supposed to apply to ice particles. By suitable assumptions about the vertical currents these processes are made to give a distribution of charge agreeing with the Kew alti-electrograph records of Simpson, Scrase and Robinson. The breaking-drop process is supposed to contribute a small effect at temperatures above the freezing point, but no use is made of the frictional electrification produced by clashing of ice particles which is invoked by Simpson and Scrase.

The assumptions on the vertical currents are supported by a good deal of information gathered during flights by gliders in thunderstorms at the Rhon glider meeting in 1938. These flights provided much interesting information on the vertical currents, hail and icing in thunderclouds. The vertical currents, referred to as "chimneys" from their shape, were smooth in the centre but turbulent on their edges. Large clouds contained more than one "chimney". Hail, encountered up to heights of over 8 Km., increased in size and weight with height and was very destructive.

Other sections of the book deal with the propagation of the lightning discharge following Toepler's theory, the electric field of thunderclouds and the electric field charges produced by lightning strokes.

A final chapter deals on normal lines with atmospheric and the maintenance of the earth's electric charge.

G. A. BULL

The formation and the development of occluding cyclones : a study of surface weather maps. By K. R. Postma. *Meded. Verh. Ned. met. Inst., De Bilt, Serie B, 1, Nr. 10.* 4to. 12½ in. × 9 in. pp. iv+57, *Illus.* Staatsdrukkerij-en Uitgeverijbedrijf, The Hague, 1948, Price : 5 florins.

This is a paper on the kinematics of fronts and depressions.

In the course of his researches from 1938 onwards the author found, as others had already done, that there are substantial differences between the fronts on the published charts of European meteorological services, and that often no evidence could be found in the autographic records or observations of stations for fronts which according to the published charts (the Dutch, Bergen and Deutsche Seewarte are specifically mentioned) had passed over them.

He strongly attacks the drawing for "historical" or conventional reasons of fronts in positions for which there are no clear observations. He is particularly concerned with the conventional Norwegian assumption that the occlusion passes through the centre of the associated depression and that the "crest" of the so called wave depression is necessarily a low-pressure centre.

Taking the occluded depression, he gives a detailed kinematical study, based on gradient wind trajectories, of the displacement of a front initially extending out from the centre of a moving depression, and shows that the front would within a very few hours no longer pass through the centre and that the twisting effect is so great near the centre as to make recognition of fronts impossible. He also argues against the possibility of the centre being on the occlusion from the fact that at a station north-east of the centre of an eastward moving depression and in the loop of the occlusion the wind at the second passage of the front would back and not veer. As a corollary to this there follows the non-existence of the back-bent occlusion.

He next considers the formation of a warm sector in an initially straight front, and shows that if there is a fall of surface pressure due to high level disturbance on or to the north of the front the consequent air motion will lead to a bulge in the front which, opposed to the normal theory, is a consequence and not the cause of the fall of pressure. Detailed diagrams based on gradient wind trajectories and circular isobars as before are drawn to show the movement of the front. If the fall of pressure moves rapidly parallel to the front the bulge in the front travels rapidly along with the fall of pressure as an open "wave", the so-called stable wave ; otherwise the motion corresponds to the so-called unstable occluding type. The effects of departure of the wind from the gradient value are not considered. A very good example of the rapid motion of a shallow wave on a quasi-stationary front, from the Atlantic to central Europe on February 3-4, 1948, is given, illustrated with seven charts. On this occasion a marked trough of low pressure well to the north of the front moved eastwards with the wave which, from the detailed observations plotted, at no time had a closed isobar at the crest.

The Atlantic charts for the period of the international swell observations, November 13-18, 1938, are also given, analysed at the time according to

conventional Norwegian methods, and re-analysed by the author, with no fronts passing through the low-pressure centres. Observations are given only on the re-analysed charts. Comparison would have been facilitated if they had also been given on the original "Norwegian" ones.

The paper does not throw much light on the physics of depressions but is certainly worthy of study by synoptic meteorologists.

G. A. BULL

Rockets and space travel. By Willy Ley. 16 mo. 8 in. $\times$ 5½ in. pp. viii + 374, *Illus.* Chapman & Hall, Ltd., London. 1949. Price : 18s. od.

This is a popular book by a German rocket pioneer for those who are interested in rockets as such.

Much of the book is devoted to the history of the development of rockets from Chinese fireworks to the V2.

One chapter is devoted to a proposal for a meteorological rocket. This rocket is of the liquid-fuel type with a combustion chamber at the nose and the fuel tanks behind with a weight of 100 lb. and length of 10 ft. The purpose of the rocket is to carry radio-sondes rapidly up to any pre-set height from which they would drift down with the silent rocket by parachute, telemetering observations all the while. Such a device could be imagined for use over a desert, but could not be used over inhabited country. If rockets are ever used for routine meteorological ascents, the expendable powder rocket is more likely to be used than the complicated and expensive liquid-fuel rocket.

D. D. CLARK

WEATHER OF APRIL 1949

During the first week deep depressions were centred not far to the west and north of the British Isles, and one passed eastwards across the British Isles between the 5th and 6th. This was followed by an anticyclone, which drifted away to the continent on the 10th. During the rest of the month depressions mostly kept well to the north and north-west of Scotland, and anticyclones often extended north-eastwards from the Azores to cover the southern parts of England and Ireland.

Mean pressure for the month was about 1020 mb. over southern Europe and 1000 mb. near the east coast of Greenland. It was mostly between 1010 mb. and 1020 mb. in North America, where it differed little from the normal. In southern Europe it was between 5 and 10 mb. above the normal, and east of Greenland between 10 and 15 mb. below normal.

The weather over the British Isles was warm generally; it was very sunny in eastern and central districts but excessively wet in the mountainous districts of the western Highlands, the Lake District and Wales.

The first ten days of the month were very unsettled with widespread gales on the 3rd, 4th, and 7th. From the 1st to 5th troughs of low pressure associated with Atlantic depressions moved north-east over the country giving rain, which was heavy locally at times, particularly on the 3rd and 5th (4.10 in. at Borrowdale and 3.85 in. at Thirlmere, Cumberland, on the 3rd and 2.91 in. at Rhondda Water Works and 2.40 in. at Treherbert, Glamorgan, on the 5th). On the 5th and 6th a depression moved rapidly across south Ireland and northern England to the southern Baltic and on the 6th and 7th another moved rapidly across England to south Sweden. Rain, heavy in places, fell generally on the 6th, while wintry showers occurred on the 7th, with thunder

locally in the west Midlands. Rather widespread gales were recorded in England and north-west Ireland on the 7th. In the rear of the latter depression a polar air stream flowed over the British Isles and temperature fell considerably. From the 8th to 10th an anticyclone off our northly-west coasts moved rather quickly south-east and a short period of mainly fair weather prevailed, though rain was renewed in the west and north by the evening of the 9th, and on the 10th a cold front off the west coast of Ireland moving north-east caused considerable rainfall locally in the west and north-west. During the ensuing days pressure was low to the north and high to the south of the British Isles and a westerly type of weather prevailed with rain in the west but little or none in east Britain.

On the 14th and 15th an anticyclone over France moved north-east, while troughs of low pressure approached our western seaboard. Our air supply was drawn from the south, temperature rose considerably and fair weather prevailed over much of the country except Ireland and west and north Scotland. By the 15th, day temperature was unusually high for the time of year in some western districts and on the 16th, Easter Saturday, in eastern districts. The maximum temperature on the 16th reached 84°F. at Greenwich and 85°F. at Camden Square; the Greenwich figure was the highest in April since records began in 1841. Thunderstorms occurred locally in north-east England on the night of the 16-17th. During the following days temperature was lower but still much above the average in most districts. Over a substantial area in the south-east the Easter period was the warmest and probably the sunniest on record. On the 18th a weak trough of low pressure moving north-east brought slight rain to the northern half of the country, while on the 19th a trough moving south-east caused some rain, mainly slight, in the west and north. Meanwhile fair weather continued in the south. On the 20th and 21st a depression moved from mid-Atlantic to a position west of Scotland and thence to the North Sea; rain fell generally though not until the night of the 20-21st in England and Wales, where sunshine was abundant on the 20th. On the 22nd a trough of low pressure moving quickly east over Scotland was associated with heavy rain in Argyllshire and Inverness-shire (2.70 in. at Ardgour House, 2.80 in. at Loch Quoich and 2.60 in. at Fort William).

During the remainder of the month unsettled weather prevailed with depressions moving north-east or east to the north of the British Isles and associated troughs crossing the country. Gales were recorded in the north of Scotland on the 27th and 28th and rain or showers occurred at times, but there were also considerable amounts of bright sunshine. Thunder was recorded locally on the 25th.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	85	25	+4.3	120	—1	114	41
Scotland	75	26	+3.2	149	+4	97	32
Northern Ireland..	65	27	+3.6	118	+2	90	32

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, DECEMBER 1948

STATIONS	PRESSURE		TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE			
	Mean of day M.S.L.	Diff. from normal	Mean values				Total	Diff. from normal			Days	Daily mean	Per- centage of possible			
			Absolute		Max.	Min.								Max. 1/2 and Min.	Diff. from normal	Wet bulb
			Max.	Min.												
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.	hr.	%		
1017.8	+5.2	56	22	48.0	39.6	43.8	+2.3	41.7	86	7.2	2.02	2.02	1.4	18		
1021.1	+0.8	72	48	63.6	55.5	59.5	+3.5	56.6	89	7.7	5.77	5.77	3.6	37		
1021.7	+5.5	66	46	61.6	51.6	56.6	-1.3	55.6	93	6.3	7.42	7.42	4.5	46		
1015.1	-0.7	73	56	68.8	57.6	63.2	+2.3	57.9	85	9.5	0.97	0.97	—	—		
1011.3	—	91	62	87.0	71.3	79.1	—	72.7	88	5.3	0.13	0.13	—	—		
Lagos, Nigeria	1010.5	0.0	68	91.2	70.4	80.8	-1.0	76.7	89	7.8	0.00	0.00	5.7	49		
Kaduna, Nigeria	1011.1	—	93	87.9	57.9	72.9	-1.4	54.2	19	3.1	0.00	0.00	8.9	77		
Chileka, Nyasaland	1012.6	0.0	94	87.7	68.1	77.9	+1.8	67.6	63	5.8	1.86	1.86	6.8	52		
Lusaka, Rhodesia	1010.5	0.0	81	84.4	62.8	73.6	+1.8	64.2	65	6.5	2.68	2.68	5.2	40		
Salisbury, Rhodesia	1011.4	-0.1	88	82.4	59.6	71.0	+1.6	60.2	54	4.4	2.23	2.23	5.9	45		
Cape Town...	1015.6	+1.3	83	76.7	59.7	68.2	+0.3	58.8	60	4.1	0.62	0.62	—	—		
Germiston, South Africa	1010.2	-1.9	92	83.1	58.7	70.9	+3.8	57.1	46	3.0	0.73	0.73	9.7	72		
Mauritius	1015.2	-0.4	84	78.3	57.3	67.8	+1.3	59.7	82	0.8	0.00	0.00	9.5	88		
Calcutta, Alipore Obsy.	1012.8	-0.7	91	87.3	70.5	78.9	+1.5	67.0	72	1.7	0.00	0.00	9.8	90		
Bombay	1013.0	-0.5	86	82.5	69.7	76.1	-0.6	69.8	84	6.1	1.70	1.70	7.3	65		
Madras	1010.4	+0.1	90	85.7	72.6	79.1	-0.4	72.7	90	6.7	5.22	5.22	5.3	45		
Colombo, Ceylon	1009.8	+0.1	93	87.6	74.0	80.8	+0.9	75.6	83	7.1	13.58	13.58	—	—		
Singapore	1012.9	-6.8	80	71.9	63.2	67.5	+4.5	63.3	83	—	0.80	0.80	—	—		
Hongkong	1012.8	+0.9	95	75.9	62.7	69.3	-0.8	63.6	66	6.3	3.77	3.77	4.2	39		
Sydney, N.S.W.	1012.1	-0.6	98	78.1	53.9	66.0	+1.2	57.2	53	7.7	1.72	1.72	5.6	38		
Melbourne	1013.6	+0.3	99	78.7	57.8	68.3	-2.8	57.5	41	7.7	1.09	1.09	7.6	53		
Adelaide	1013.9	+0.7	94	77.7	58.6	68.1	-2.7	60.1	55	3.0	0.67	0.67	10.0	70		
Perth, W. Australia	1014.0	+2.0	90	83.4	68.3	75.9	-0.5	68.9	69	6.3	3.21	3.21	8.0	58		
Coalgardie	1007.5	-2.2	91	69.2	49.7	59.5	-0.7	52.3	52	5.8	1.84	1.84	8.0	52		
Brisbane	1007.1	-1.5	85	81.3	73.5	77.4	-1.6	74.0	84	8.6	15.74	15.74	4.2	32		
Hobart, Tasmania	1006.7	-1.2	88	85.1	74.1	79.6	-0.4	77.7	86	8.5	32.92	32.92	5.1	40		
Wellington, N.Z.	1014.7	+0.7	92	88.2	70.4	79.3	+1.6	68.7	86	2.3	0.32	0.32	8.6	77		
Suva, Fiji	—	—	85	70	74.8	79.4	+1.2	74.2	78	8.4	2.28	2.28	—	—		
Apia, Samoa	1017.3	-0.3	52	-1	37.4	31.5	+4.4	27.0	75	8.8	2.12	2.12	2.5	28		
Kingston, Jamaica	1016.5	-2.2	37	-27	14.4	6.1	+0.3	4.0	75	6.9	1.63	1.63	2.6	32		
Grenada, W. Indies	1015.1	+1.1	51	3	35.8	29.2	+4.8	24.7	85	6.4	4.20	4.20	4.2	48		
Toronto	1013.5	-3.2	51	20	30.4	35.8	-5.3	33.1	88	7.5	6.30	6.30	2.1	25		
Winnipeg																
St. John, N.B.																
Victoria, B.C.																

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, YEAR 1948

STATIONS	PRESSURE		TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE	
	Mean of day M.S.L.	Diff. from normal	Mean values				Wet bulb	Total			Diff. from normal	Days	Daily mean	Per- centage of possible
			Max.	Min.	Max. 1 and 2	Diff. from normal								
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	tenths	in.	in.	hr.	%	
London, Kew Observatory	1016.3	+1.4	93	22	45.0	51.5	47.8	80	7.2	21.45	-2.35	145	32	
Gibraltar ..	1018.7	+0.8	92	42	60.2	66.1	61.6	82	5.2	25.33	—	84	64	
Malta ..	1017.2	+1.8	96	44	59.0	65.2	62.2	71	4.4	23.17	—	76	72	
St. Helena ..	1016.7	-0.4	81	52	67.3	62.5	57.8	94	9.0	32.86	+1.22	178	—	
Lungi, Sierra Leone	1012.1	—	94	62	73.9	79.1	74.6	86	6.8	141.60	—	167	—	
Lagos, Nigeria	1012.0	+1.2	94	60	70.5	78.9	75.9	84	8.2	35.95	—	112	39	
Kaduna, Nigeria	1010.5	—	99	54	64.9	76.3	65.2	54	6.2	50.87	-2.96	105	61	
Chileka, Nyasaland ..	1016.6	+0.1	97	48	81.9	72.5	64.8	66	4.6	32.70	-3.38	80	56	
Lusaka, Rhodesia ..	1014.1	+0.3	97	43	58.6	69.4	60.4	66	4.8	34.48	-2.79	92	62	
Salisbury, Rhodesia ..	1016.1	0.0	91	35	54.4	65.4	57.2	64	3.8	31.80	-1.64	96	61	
Cape Town	—	—	103	33	—	—	—	—	—	23.07	-1.97	136	—	
Germiston, South Africa	1017.9	+0.6	92	24	50.3	61.6	50.6	61	2.9	20.40	-5.14	77	75	
Mauritius	1006.9	-0.7	100	53	88.4	80.3	73.2	85	5.0	67.49	+3.17	130	57	
Calcutta, Alipore Obsv.	1008.3	-0.9	95	61	87.7	81.7	74.0	80	4.7	71.74	-0.45	91	60	
Bombay ..	1008.3	-0.5	110	65	92.1	84.3	74.9	77	5.8	34.09	-15.47	82	65	
Madras	1010.1	+0.4	92	69	86.7	80.9	75.1	87	6.5	74.85	-5.28	188	60	
Colombo, Ceylon ..	1009.6	+0.1	95	71	87.7	81.4	76.6	83	7.3	104.78	+9.66	197	—	
Singapore ..	1012.5	0.0	92	39	78.5	73.7	69.2	82	—	97.75	+12.02	180	51	
Hongkong	1015.8	-0.1	97	38	70.4	62.9	56.5	67	5.1	38.83	-8.65	129	72	
Sydney, N.S.W.	1015.5	-0.8	104	30	67.1	58.0	51.6	65	6.4	20.98	-4.49	155	45	
Melbourne ..	1017.6	+0.5	110	37	70.2	61.3	53.4	57	6.2	21.40	+0.25	122	54	
Adelaide	—	—	107	39	74.6	65.1	58.3	60	4.1	34.75	+0.38	115	64	
Perth, W. Australia ..	1015.9	0.0	96	37	77.3	68.4	61.3	65	4.4	41.54	-3.75	106	67	
Coalgardie ..	—	—	—	—	—	—	—	—	—	—	—	—	—	
Brisbane ..	—	—	—	—	—	—	—	—	—	—	—	—	—	
Hobart, Tasmania	1010.8	-0.5	91	60	81.6	76.9	73.2	83	7.5	120.40	+3.26	243	41	
Wellington, N.Z.	1009.9	-0.1	93	67	86.1	79.9	76.9	80	6.8	141.48	+29.48	238	55	
Suva, Fiji ..	1013.7	0.0	95	65	89.4	81.0	73.9	75	3.9	37.82	+4.23	65	68	
Apia, Samoa ..	—	—	—	—	—	—	—	—	—	—	—	—	—	
Kingston, Jamaica ..	—	—	—	—	—	—	—	—	—	—	—	—	—	
Grenada, W. Indies ..	1017.2	+0.6	101	12	55.6	47.7	40.7	79	7.5	57.35	-17.24	241	—	
Toronto ..	1015.6	-0.6	95	-36	46.9	36.7	28.4	74	6.5	28.44	-2.85	127	45	
Winnipeg ..	1015.9	+1.3	87	-15	49.5	41.7	37.1	86	5.5	15.92	-4.26	104	50	
St. John, N.B.	1016.3	-0.4	81	20	55.2	48.1	42.5	86	6.4	48.88	+0.80	175	43	
Victoria, B.C.	—	—	—	—	—	—	—	91	6.4	43.28	+12.97	165	47	

RAINFALL OF APRIL 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	1·65	107	<i>Glam.</i>	Cardiff, Penylan ..	3·02	121
<i>Kent</i>	Folkestone, Cherry Gdn.	1·85	111	<i>Pemb.</i>	St. Ann's Head ..	2·89	141
<i>"</i>	Edenbridge, Falconhurst	1·79	96	<i>Card.</i>	Aberystwyth ..	3·29	160
<i>Sussex</i>	Compton, Compton Ho.	2·23	111	<i>Radnor</i>	Tyrmynydd ..	5·13	139
<i>"</i>	Worthing, Beach Ho.Pk.	1·16	74	<i>Mont.</i>	Lake Vyrnwy ..	7·33	228
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	1·17	70	<i>Mer.</i>	Blaenau Festiniog ..	11·41	185
<i>"</i>	Bournemouth ..	1·78	99	<i>Carn.</i>	Llandudno ..	2·12	125
<i>"</i>	Sherborne St. John ..	1·91	108	<i>Angl.</i>	Llanerchymedd ..	2·50	113
<i>Herts.</i>	Royston, Therfield Rec.	1·60	102	<i>I. Man.</i>	Douglas, Borough Cem.	3·24	133
<i>Bucks.</i>	Slough, Upton ..	1·17	82	<i>Wigtown</i>	Port William, Monreith	2·69	122
<i>Oxford</i>	Oxford, Radcliffe ..	1·31	82	<i>Dumf.</i>	Dumfries, Crichton R.I.	2·97	126
<i>N'hant.</i>	Wellingboro', Swanspool	1·53	103	<i>"</i>	Eskdalemuir Obsy. ..	6·45	190
<i>Essex</i>	Shoeburyness ..	1·35	112	<i>Roxb.</i>	Kelso, Floors ..	1·35	86
<i>Suffolk</i>	Campsea Ashe, High Ho.	1·23	87	<i>Peebles</i>	Stobo Castle ..	2·56	123
<i>"</i>	Lowestoft Sec. School ..	1·33	90	<i>Berwick</i>	Marchmont House ..	1·02	50
<i>"</i>	Bury St. Ed., Westley H.	1·84	120	<i>E. Loth.</i>	North Berwick Res. ..	·98	70
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·19	144	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	1·07	73
<i>Wilts.</i>	Bishops Cannings ..	1·34	66	<i>Lanark</i>	Hamilton W. W., T'nhill	3·14	168
<i>Dorset</i>	Creech Grange ..	1·98	92	<i>Ayr</i>	Colmonell, Knockdolian	4·06	160
<i>Devon</i>	Beaminster, East St. ..	2·29	97	<i>"</i>	Glen Afton, Ayr San ..	5·62	187
<i>"</i>	Teignmouth, Den Gdns.	1·55	77	<i>Bute</i>	Rothsay, Ardenraig ..	6·77	227
<i>"</i>	Cullompton ..	1·82	80	<i>Argyll</i>	L. Sunart, Glenborrodale	8·20	196
<i>"</i>	Barnstaple, N. Dev. Ath.	2·10	99	<i>"</i>	Poltalloch ..	6·36	211
<i>"</i>	Okehampton, Uplands	3·09	97	<i>"</i>	Inverary Castle ..	12·36	269
<i>Cornwall</i>	Bude School House ..	1·79	95	<i>"</i>	Islay, Eallabus ..	6·10	213
<i>"</i>	Penzance, Morrab Gdns.	1·85	76	<i>"</i>	Tiree ..	5·46	222
<i>"</i>	St. Austell, Trevarna ..	1·86	66	<i>Kinross</i>	Loch Leven Sluice ..	2·29	119
<i>"</i>	Scilly, Tresco Abbey ..	1·23	63	<i>Fife</i>	Leuchars Airfield ..	·98	62
<i>Glos.</i>	Cirencester ..	1·71	91	<i>Perth</i>	Loch Dhu ..		
<i>Salop.</i>	Church Stretton ..	2·52	116	<i>"</i>	Crieff, Strathearn Hyd.	2·59	118
<i>"</i>	Cheswardine Hall ..	2·47	141	<i>"</i>	Pitlochry, Fincastle ..	2·78	125
<i>Worcs.</i>	Malvern, Free Library	2·40	133	<i>Angus</i>	Montrose, Sunnyside ..	1·95	107
<i>Warwick</i>	Birmingham, Edgbaston	2·39	137	<i>Aberd.</i>	Braemar ..	2·28	96
<i>Leics.</i>	Thornton Reservoir ..	2·45	144	<i>"</i>	Dyce, Craibstone ..	·92	45
<i>Lincs.</i>	Boston, Skirbeck ..	1·79	133	<i>"</i>	Fyvie Castle ..	1·19	56
<i>"</i>	Skegness, Marine Gdns.	2·11	157	<i>Moray</i>	Gordon Castle ..	1·28	73
<i>Notts.</i>	Mansfield, Carr Bank ..	1·78	103	<i>Nairn</i>	Nairn, Achareidh ..	2·08	149
<i>Derby</i>	Buxton, Terrace Slopes	4·74	161	<i>Inver's</i>	Loch Ness, Foyers ..	2·56	118
<i>Ches.</i>	Bidston Observatory ..	2·50	153	<i>"</i>	Glenquoich ..	15·40	237
<i>Lancs.</i>	Manchester, Whit. Park	2·64	137	<i>"</i>	Fort William, Teviot ..	12·00	267
<i>"</i>	Stonyhurst College ..	5·28	195	<i>"</i>	Skye, Duntuilum ..	5·12	158
<i>"</i>	Blackpool ..	2·98	159	<i>R. & C.</i>	Ullapool ..	3·81	126
<i>Yorks.</i>	Wakefield, Clarence Pk.	2·06	123	<i>"</i>	Applecross Gardens ..	5·47	160
<i>"</i>	Hull, Pearson Park ..	2·19	140	<i>"</i>	Achnashellach ..	11·73	219
<i>"</i>	Felixkirk, Mt. St. John	2·29	137	<i>"</i>	Stornoway Airfield ..	4·19	145
<i>"</i>	York Museum ..	2·48	155	<i>Suth.</i>	Lairg ..		
<i>"</i>	Scarborough ..	2·00	128	<i>"</i>	Loch More, Achfary ..	7·88	163
<i>"</i>	Middlesbrough ..	2·02	147	<i>Caith.</i>	Wick Airfield ..	1·75	88
<i>"</i>	Baldersdale, Hury Res.	3·50	145	<i>Shetland</i>	Lerwick Observatory ..	3·25	142
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	1·36	86	<i>Ferm.</i>	Crom Castle ..	3·11	121
<i>"</i>	Bellingham, High Green	1·77	82	<i>Armagh</i>	Armagh Observatory ..	2·18	104
<i>"</i>	Lilburn Tower Gdns. ..	1·10	56	<i>Down</i>	Seaforde ..	2·17	83
<i>Cumb.</i>	Geltsdale ..	2·98	140	<i>Antrim</i>	Aldergrove Airfield ..	1·94	92
<i>"</i>	Keswick, High Hill ..	7·17	234	<i>"</i>	Ballymena, Harryville ..	2·56	97
<i>"</i>	Ravenglass, The Grove	3·31	133	<i>L'derry</i>	Garvagh, Moneydig ..	2·46	101
<i>Mon.</i>	Abergavenny Larchfield	3·01	119	<i>"</i>	Londonderry, Creggan	5·10	198
<i>Glam.</i>	Ystalyfera, Wern House	5·78	152	<i>Tyrone</i>	Omagh, Edenfel ..	3·78	144

METEOROLOGICAL OFFICE

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A PRELIMINARY CLASSIFICATION OF ANTICYCLONES BY MEANS OF THE THICKNESS PATTERN

BY J. S. SAWYER, M.A.

With the recent increase in the number of upper air soundings, thickness charts are employed by the weather forecaster to an increasing extent in determining the likely development of the synoptic situation (see Sutcliffe^{1*}). Considerable success has been achieved in forecasting the behaviour of depressions in this way, and the significance of several types of thickness pattern which may occur over depressions is recognised. This note contains a preliminary classification of the main types of thickness patterns which occur over anticyclones; the classification is neither complete nor final, but is thought to be sufficiently well established to provide useful practical guidance in many synoptic situations.

In order that the cases examined should be reasonably clear cut, the study was confined to anticyclones which could be identified by 4-mb. isobars over a 24-hr. period. The centre was also restricted to lie between latitudes 40° and 60°N. and longitudes 0° and 50°W., *i.e.* over the eastern North Atlantic or seaboard of western Europe.

Classification of anticyclones.—In relation to the pattern of the 1000–500-mb. thickness lines the majority of anticyclones appear to fall into three types with distinct thickness patterns; a fourth type is also suggested, but the number of cases is insufficient to establish it with certainty. About one quarter of the examples fell into none of the four types. The behaviour of each type of anticyclone had certain broadly recognisable characteristics; these are set out below together with the thickness patterns which form the basis of the classification. How far these generalizations are justified may be assessed from Tables I–III in which the motion and change of intensity of the anticyclones are tabulated according to type. The tables contain two sets of data; the first, for the period October 1946 to April 1948, formed the basis of the classification; the second, May to September 1948, was analysed subsequently by Mr. A. G. Matthewman and may be regarded as an independent check of the validity of the classification. An entry is included in the tables for each 24-hr. period over which any anticyclone persisted in the area covered.

*These numbers refer to the list of references on p. 93.

The classification proposed is as follows.

Type 1—Open wave type (see Fig. 1).—The features of the thermal field are:—

(a) Strong thermal wind over the centre (usually 40–50 kt. over the range 1000–500 mb.)

(b) Flat “wave” pattern of thickness lines with the anticyclonic centre between a “thermal ridge” and the next “thermal trough” in the direction of the thermal wind (for this purpose a “flat” wave pattern may be regarded as one in which the maximum inclination to the general stream is less than 45°).

The simultaneous behaviour of the centre is:—

(i) Fast motion towards the “thermal trough”. The average speed is about 25 kt. but varies over a wide range; motion is in a direction roughly perpendicular to the trough line but there appears to be a tendency to move toward the region where the thermal wind is strongest.

(ii) Central pressure may rise or fall slowly; possibly, rising pressure is slightly more frequent.

Type 2—Distorted wave type (see Fig. 2).—The features of the thermal field are:—

(a) Strong thermal wind over the centre; usually 40–50 kt. when taken over the range 1000–500 mb.

(b) a “wave” pattern of wide amplitude in the thickness lines with the anticyclonic centre between a “thermal ridge” and the next “thermal trough” in the direction of the thermal wind. The difference between this type and the preceding type is in the distortion of the wave pattern which should twist the thickness lines to an angle of more than 45° from the general stream, *i.e.* from the general direction of the thickness lines over a wide area over which the distortion in the region of the anticyclone can be ignored.

The simultaneous behaviour of the pressure centre is:—

(i) Slow motion (10–25 kt.) towards the “thermal trough”. The direction is usually inclined to the right of the perpendicular to the trough line, but involves displacement across the thickness lines into the cold air.

(ii) Central pressure changing little or rising slowly.

Type 3—Warm anticyclone (see Fig. 3). The features of the thermal field are:—

(a) Very weak thermal gradients near the anticyclonic centre.

(b) Anticyclonic centre lies on or near the axis of the warm tongue.

The characteristic behaviour is:—

(i) Very slow motion (usually less than 10 kt.).

(ii) Direction of motion usually in a direction between the axis of the warm tongue towards the higher temperature and the direction from the anticyclone centre to the apex of the cold trough.

(iii) Little change in central pressure.

Type 4—Diffluent ridge type (see Fig. 4). This type is not clearly defined because of lack of examples. Its main features are similar to Type 3 but it differs in that the next thermal trough is advancing towards the anticyclone centre. The thermal gradient is intensified on this side of the warm ridge and weak on the other.

The motion of the centre is in a similar direction to that of Type 3 but quicker (15–20 kt.); the central pressure decreases, sometimes rapidly.

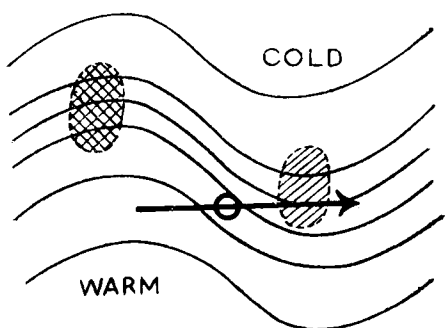


FIG. 1

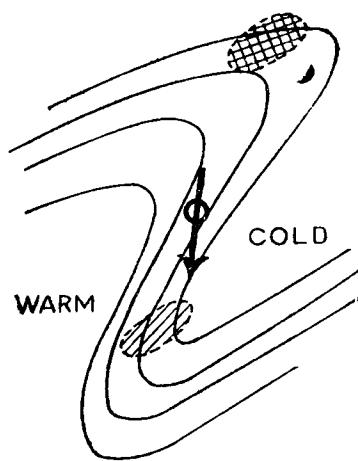
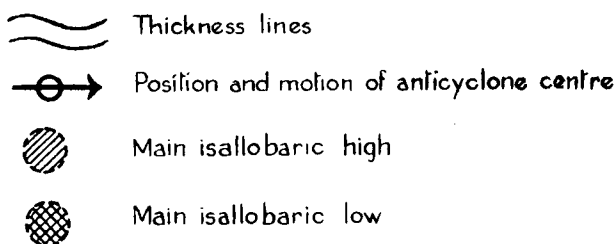


FIG. 2

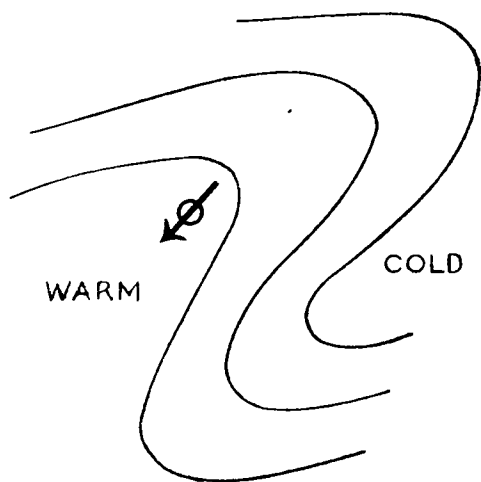


FIG. 3

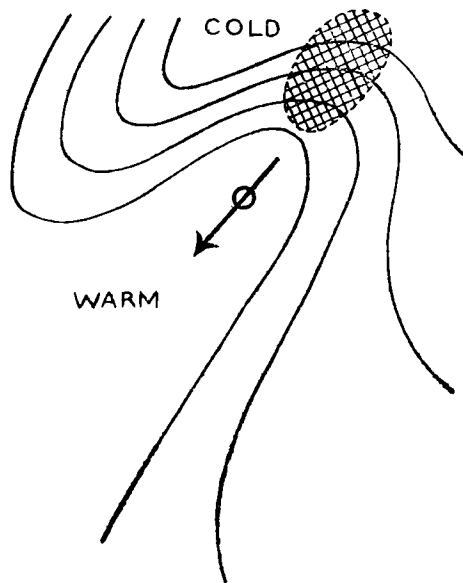


FIG. 4

Discussion of the results.—By the choice of area, cold polar and continental anticyclones have been excluded; so also have the subtropical highs when in their normal position.

The restriction to centres defined by 4-mb. isobars over a 24-hr. period also excluded, among others, those in the early stages of anticyclogenesis and the late stages of dissolution. Of the remainder, about three quarters could be classified according to the scheme now proposed.

The behaviour of the various types is explicable on the theoretical basis of Sutcliffe². The classification is also consistent with the older conception of "cold" and "warm" anticyclones (Brunt³, Douglas⁴). The transformation

TABLE I—NUMBER OF CASES IN WHICH ANTICYCLONES OF VARIOUS TYPES MOVED DISTANCES WITHIN CERTAIN RANGES

(a) Number of anticyclones in period October 1946 to April 1948
(b) Number of anticyclones in period May to September 1948

Type of anticyclone	Distance moved in 24 hr. (nautical miles)							
	0-150		150-350		350-550		Over 550	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	0	0	4	0	8	0	11	2
2	5	2	6	3	6	3	1	0
3	14	4	14	5	3	0	0	0
4	1	0	0	0	2	0	3	0
Unclassified	7	2	5	4	3	3	4	3

TABLE II—NUMBER OF CASES IN WHICH CHANGE OF CENTRAL PRESSURE FELL WITHIN CERTAIN RANGES

(a) Number of anticyclones in period October 1946 to April 1948
(b) Number of anticyclones in period May to September 1948

Type of anticyclone	Change in central pressure in 24 hr. (mb.)					
	-3 or less		-2 to +2		+2 or more	
	(a)	(b)	(a)	(b)	(a)	(b)
1	3	1	15	1	5	0
2	2	1	12	6	4	1
3	8	0	19	9	4	0
4	2	0	4	0	0	0
Unclassified	5	1	11	8	3	3

TABLE III—NUMBER OF CASES OF ANTICYCLONES WITH MOTION DIRECTED IN CERTAIN QUADRANTS WITH RESPECT TO THE THERMAL FIELD

(a) Number of anticyclones in period October 1946 to April 1948
(b) Number of anticyclones in period May to September 1948

Type of anticyclone	Indeterminate†		Direction (degrees)*							
			+45 to -45		-45 to -135		-135 to +135		+135 to +45	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
1	0	0	19	1	4	0	0	0	0	1
2	5	3	10	2	2	2	0	0	1	1
3	14	3	8	2	6	1	0	0	3	3
4	1	0	0	0	5	0	0	0	0	0
Unclassified	7	4	5	5	1	3	4	0	2	0

*Direction is measured with respect to a line drawn perpendicular to the main trough and ridge lines of the thermal field, the positive direction being taken in the direction of the thermal wind.

†Includes all cases of 150 nautical miles or less motion in 24 hr.

of a "cold" moving anticyclone into a slow-moving "warm" anticyclone can be regarded as a transition from Type 1 through Type 2 to Type 3. The recent classification due to Seilkopf⁶ is broadly similar to the present one, but includes additional types.

No attempt is made here to draw general conclusions with validity outside the limited area and types of situation studied; however, the evidence supports the view that while "thermal steering" may be applied broadly to anticyclones in well defined and sensibly straight thermal patterns, it can be seriously misleading in other cases. The same generalization is known to be true for depressions.

Acknowledgement.—I wish to acknowledge the assistance given by Mr. A. G. Matthewman in the preparation of this paper and in particular his analysis of the anticyclones of the period May to September 1948; also the help given by Miss D. L. Barnes in collecting the data.

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SEASONAL WEATHER SEQUENCES OVER ENGLAND AND WALES

By J. GLASSPOOLE, M.Sc., Ph.D.

While it is well known that dry winters may be followed either by dry, average or wet summers, no table is readily available showing the frequencies of such occurrences. The estimates of general monthly rainfall over England and Wales, which are available back to 1870, provide the material for preparing such a table and this note sets out the results of examining these records. The general monthly values, as published in the annual volumes of *British Rainfall*, are the best available estimates of the mean rainfall over the country, *i.e.* the estimated mean depth in inches of the varying rainfall amounts over the various districts. The monthly values in inches were grouped to give the total amount in each meteorological winter, defined as covering December to February; in each spring—March to May; in summer—June to August; and in autumn—September to November. The rainfall of each season was regarded as “average” when it was within 5 per cent. of the mean, “wet” when from 105 to 130 per cent., and “very wet” when more than 130 per cent. of the average. Similarly the limits 95–70 per cent. and less than 70 per cent. were used to denote “dry” and “very dry”.

In Table I details of the nature and frequency of the springs, summers and autumns following the five different types of winters are listed for the 79 years December 1869 to November 1948.

The table shows that there is very little difference in the rainfall types of either the spring, summer or autumn following winters which were very wet, wet, average, dry or very dry. The subsequent seasons gave less rather than more than the average, when the preceding winters were very wet, average or dry in the case of springs; average, dry or very dry in the case of summers, and wet or dry in the case of autumns. This again indicates that the rainfall of the following seasons is not determined by the rainfall of the winter. The table brings out that dry winters have been followed by dry springs, summers and autumns, rather more often than by wet ones.

The results are in accord with an earlier examination* of the persistence of dry or wet months, when the general conclusions were: (a) runs of five or more months, either all above or all below the average, are rather more frequent

*BILHAM, E. G. ; Sequences of dry and wet months in England and Wales. *Quart. J. R. met. Soc.*, London, **64**, 1938, p. 324.

TABLE I—OCCASIONS OF SEASONAL RAINFALLS FOLLOWING WINTERS OF DIFFERENT TYPES

Winters		Spring	Summer	Autumn
Very wet (12 cases)	very wet	1 } 4	1 } 6	1 } 6
	wet	3 } 4	5 } 6	5 } 6
	average	2	2	0
	dry	5 } 6	3 } 4	5 } 6
	very dry	1 } 6	1 } 4	1 } 6
wet (20 cases)	very wet	2 } 9	2 } 10	2 } 5
	wet	7 } 9	8 } 10	3 } 5
	average	3	3	5
	dry	8 } 8	4 } 7	9 } 10
	very dry	0 } 8	3 } 7	1 } 10
average (11 cases)	very wet	1 } 2	2 } 4	2 } 5
	wet	1 } 2	2 } 4	3 } 5
	average	2	1	2
	dry	4 } 7	1 } 6	1 } 4
	very dry	3 } 7	5 } 6	3 } 4
dry (25 cases)	very wet	2 } 8	3 } 7	3 } 10
	wet	6 } 8	4 } 7	7 } 10
	average	5	4	2
	dry	9 } 12	9 } 14	10 } 13
	very dry	3 } 12	5 } 14	3 } 13
very dry (11 cases)	very wet	2 } 7	2 } 4	1 } 5
	wet	5 } 7	2 } 4	4 } 5
	average	1	2	1
	dry	3 } 3	3 } 5	5 } 5
	very dry	0 } 3	2 } 5	0 } 5

than chance would indicate; and (b) runs of three or more dry months are distinctly more frequent than runs of three or more wet months.

Similar general values for temperature for England and Wales are available only since 1901*. The general values of temperature, as published in the *Monthly Weather Report*, are obtained by taking the mean of the departures from average at 30 well distributed stations and applying these means to the general monthly mean temperatures computed for England and Wales. In the following table, months with temperatures within 0.5°F. of the average are counted as "average", months with an excess of 2°F. as "much above" and with temperatures of 2°F. below the average as "much below".

Table II shows that the temperatures of the springs, summers and autumns following winters of the various types have had on the whole no special characteristics. It will be noticed, however, that following the 14 cases of winters with temperatures "above" average, the summers were rather more often colder than average and the autumns rather more often warmer than average.

The winter of December 1948–February 1949 falls into the classification adopted here of "dry" as regards rainfall, and "much above" as regards temperature. Table I shows that of 25 earlier cases of "dry" winters the following spring was "dry" or "very dry" on 12 occasions, the following

*GLASSPOOLE, J. and HOGG, W. H.; Serial monthly values of mean temperature over the British Isles, 1881–1940, and annual values 1866–1940. *Quart. J. R. met. Soc.*, London, 69, 1942, p. 45.

TABLE II—OCCASIONS OF SEASONAL TEMPERATURES FOLLOWING WINTERS OF DIFFERENT TYPES

Winters		Spring	Summer	Autumn
much above (7 cases)	much above	1 } 3	0 } 3	0 } 2
	above	2 } 3	3 } 3	2 } 2
	average	1	1	3
	below	3 } 3	3 } 3	1 } 2
	much below	0 } 3	0 } 3	1 } 2
above (14 cases)	much above	1 } 4	1 } 4	1 } 7
	above	3 } 4	3 } 4	6 } 7
	average	7	3	5
	below	3 } 3	6 } 7	0 } 2
	much below	0 } 3	1 } 7	2 } 2
average (14 cases)	much above	0 } 4	1 } 5	1 } 6
	above	4 } 4	4 } 5	5 } 6
	average	4	3	2
	below	6 } 6	6 } 6	3 } 6
	much below	0 } 6	0 } 6	3 } 6
below (6 cases)	much above	1 } 1	0 } 2	1 } 2
	above	0 } 1	2 } 2	1 } 2
	average	2	2	2
	below	3 } 3	2 } 2	2 } 2
	much below	0 } 3	0 } 2	0 } 2
much below (7 cases)	much above	0 } 1	1 } 3	1 } 3
	above	1 } 1	2 } 3	2 } 3
	average	3	1	4
	below	1 } 3	2 } 3	0 } 0
	much below	2 } 3	1 } 3	0 } 0

summer on 14 occasions and the following autumn on 13 occasions, *i.e.* on half the occasions. Table II shows that of the 7 earlier cases of winters with temperatures “much above” average, the following springs, summers and autumns had no marked tendency as regards temperature.

Table II shows that there were 21 winters classified as “much above” or “above” with regard to temperature, and of these we find that seven were also “dry” or “very dry”. The classification of the seasons following these seven winters is given in Table III.

TABLE III—SEASONAL CHARACTERISTICS FOLLOWING MILD AND DRY WINTERS

		Spring	Summer	Autumn
Rainfall	very wet	1 } 3	2 } 2	2 } 4
	wet	2 } 3	0 } 2	2 } 4
	average	1	1	0
	dry	2 } 3	2 } 4	2 } 3
	very dry	1 } 3	2 } 4	1 } 3
Temperature	much above	0 } 5	1 } 5	0 } 3
	above	5 } 5	4 } 5	3 } 3
	average	1	0	3
	below	1 } 1	2 } 2	1 } 1
	much below	0 } 1	0 } 2	0 } 1

We see therefore that in these cases the subsequent springs, summers and autumns each varied between very wet and very dry. This was mainly due to the fact that these seven winters include both those of 1902–03 and 1920–21, the one followed by the notoriously wet 1903 and the other by the unprecedentedly dry 1921, again confirming that the rainfall and temperature of the

winter, as classified here, does not give any indication of the weather characteristics of the following seasons. Table III does, however, show a notable preponderance of temperatures above average in each season following mild and dry winters.

The only earlier occasion during the present century when the winter was classified as both “dry” and “much above”, as in 1948–1949, was that of 1920–21. This is widely remembered as being followed by an exceptionally dry and hot summer. Before jumping to any conclusion, concerning the prospects for the summer of 1949, we carry out a cautious comparison of the monthly values of these two winters, without finding any close similarity.

TABLE IV—COMPARISON IN ENGLAND AND WALES OF WINTERS 1920–21 AND 1948–49

Winter	General rainfall			Mean departure from average temperature		
	Dec.	Jan.	Feb.	Dec.	Jan.	Feb.
		<i>inches</i>			<i>degrees Fahrenheit</i>	
1920–21	3·7	4·3	0·4	+0·5	+5·3	+1·1
1948–49	4·4	1·7	1·5	+2·0	+2·1	+2·6

There is not therefore any justification in concluding that the summer of 1949 will resemble that of 1921. Indeed Nature seems capable of producing an infinite variety of sequences, and no indication has been found of any repetition likely to be of service in forecasting.

METEOROLOGICAL RESEARCH COMMITTEE

At the sixth meeting of the Physical Sub-Committee, held on May 19, the Sub-Committee heard with regret the resignation of Dr. Sutherland following his appointment to a chair of Physics at Michigan University.

A paper by Mr. R. F. Jones¹ dealing with the heights and temperatures at the tops of radar echoes associated with various cloud systems was discussed. Another paper by Dr. Frith² dealing with some measurements of cloud particle size in strato cumulus clouds was also discussed.

Mr. Shellard presented a paper³ which summarises the results of the measurement of humidity at high levels on all ascents to date by the Meteorological Research Flight.

A note⁴ on an empirical formula for the terminal velocities of raindrops was also considered.

The fifth meeting of the Instruments Sub-Committee was held on May 26. The Sub-Committee considered the possible use of “window” and of ionised clouds—in conjunction with radar—for the measurement of winds at great heights.

It was decided to try to adapt the Dobson-Brewer frost-point hygrometer for use on the ground.

Papers considered included one by Dr. Harrison⁵ dealing with the uncertainty of radar wind smoothing on ocean weather ships and a paper by Mr. Ashford⁶ on the development of marine meteorological instruments.

¹*Met. Res. Pap., London, No. 458.*
²*Met. Res. Pap., London, No. 472.*
³*Met. Res. Pap., London, No. 486.*

⁴*Met. Res. Pap., London, No. 469.*
⁵*Met. Res. Pap., London, No. 477.*
⁶*Met. Res. Pap., London, No. 481.*

OFFICIAL PUBLICATIONS

The following publications will shortly be issued:—

GEOPHYSICAL MEMOIRS

No. 83—*Wind at 100,000 ft. over south-east England.* Observations and a discussion of the monsoon theory of wind at great heights. By R. J. Murgatroyd, B.Sc.(Eng.) and C. J. B. Clews, Ph.D.

This memoir describes a series of 35 measurements of the wind at 100,000 ft. over south-east England in 1944–45 by observations of the drift of smoke produced by shell bursts from a high-velocity gun. The results indicate that the wind was mainly strong SW.–NW. in winter and moderate NE.–SE. in summer, with light winds during the change-over in spring and autumn. The mean temperature values up to 60,000 ft. from 1942 to 1945, obtained from radio-sonde ascents over Salisbury Plain and the Shetlands, indicate that in winter it is colder to the north and in summer warmer to the north; this explains the seasonal variation of wind direction in the stratosphere. The relationship between the horizontal temperature gradients, the vector mean winds over the British Isles and the wind values at 100,000 ft. are also discussed.

No. 84—*Atmospheric electricity during disturbed weather.* By Sir George Simpson, K.C.B., F.R.S.

From October 1942 to May 1946 a special investigation of atmospheric electricity during disturbed weather was undertaken at Kew Observatory with special reference to the electricity carried by rain and snow. The chief results may be summarised under three headings:—

(a) *Potential gradient and weather.*—Although the potential gradient is generally disturbed during rain or snow the disturbance is not primarily controlled by the amount or rate of the rainfall, but appears to depend on the presence of ascending currents in the upper atmosphere. Although the variations of the potential gradient during disturbed weather are usually quite irregular there are periods when the gradient plotted against time shows regular patterns which take the form of harmonic waves or of oscillations symmetrical about the mid-point of the pattern. The cause and origin of these patterns is unknown.

(b) *The electricity carried by the precipitation when the potential gradient exceeds $|20|$ v./cm.*—It is found that when the gradient exceeds $|20|$ v./cm., the charge on the rain and snow is opposite in sign to that of the potential gradient, and that the charge and the gradient increase and decrease together. It is suggested that this is because the electricity carried by the precipitation is mainly derived from the point-discharge current which originates on all pointed objects when exposed to a potential gradient greater than $|20|$ v./cm. The precipitation appears to sweep up ions from the point-discharge current as suggested by C. T. R. Wilson; but there are difficulties in this explanation for the charge observed is greater than would be expected on Wilson's theory.

(c) *The electricity carried by the precipitation when the potential gradient is less than $|10|$ v./cm.*—Low potential gradients are usually associated with light steady rain, the gradients being less than the normal fine-weather gradient and generally negative. The rain electricity in such circumstances is practically always positive and the charge per cubic centimetre is directly proportional to the depression of the gradient below its normal fine-weather value. With steady snowfall below the freezing point the gradient remains normal and the charge on the snow negative.

ROYAL AERONAUTICAL SOCIETY

Radar as an aid to the study of the atmosphere

It is well known that one of the bodies which made a great contribution to the development of radar equipment during the war was the Telecommunication Research Establishment (T.R.E.), a department of the Ministry of Supply. One of their most successful devices was that known as "Oboe", a blind aircraft navigation and bombing system used by the Pathfinders, for the development of which Dr. F. E. Jones was largely responsible. After the war T.R.E. began the process of beating their swords into ploughshares by considering possible applications of radar to meteorology, and they have been co-operating with the Meteorological Office in several projects.

A lecture on this work was given by Dr. Jones at a meeting of the Royal Aeronautical Society on January 27, 1949.

Including pulsed visible and ultra-violet light techniques in the term radar, Dr. Jones described the results achieved and hoped for under five main headings: detection of precipitation and cloud; measurement of cloud height; measurement of density in the upper atmosphere; measurement of wind; and measurement of pressure, temperature and humidity.

It is about seven years since radar echoes from rain were first observed, and a great deal of work has been and is being done on the use of radar as a means of investigating conditions within precipitating clouds and of obtaining warning of the approach of storms and rain-belts. It has been shown theoretically by Ryde that the energy scattered by a water drop is proportional to the sixth power of the diameter. If, therefore, the distribution of drop sizes were a function of the rate of rainfall, and if the function could be determined, the radar echo intensity would be a measure of the rate of rainfall. This is found to be true on the average, and data correlating drop-size distribution with rate of rainfall have been compiled by Laws and Parsons. Dr. Jones described a series of measurements made by T.R.E. on echoes from rain*, using a radar beam directed vertically upward, on a wave-length of 3.2 cm., in which the echo intensity as a function of precipitation rate agreed very well with that calculated from Laws and Parsons' data, using Ryde's theory.

In the same series of experiments observations of the so-called "bright band" were also made. This is the name given to a strong echo returned from a layer slightly below the freezing level. It has been explained by Ryde and by Hooper as being due to partially melted snowflakes, which give a stronger echo than unmelted ice crystals but have a lower speed of fall and therefore a higher concentration than water drops.

The intense convection in cumulonimbus clouds, which is such a serious danger to aircraft, produces large raindrops and therefore strong radar echoes. It is thus of interest to find out whether radar can be used to investigate the mechanism of these clouds and also to give warning of their proximity. In 1946, a party from T.R.E. flew to Singapore in a Lancaster equipped with a 3.2-cm. radar and made a study of the matter. As a result of their observations a cloud warning radar for aircraft has been designed by T.R.E. and is to undergo extensive trials. A specimen was shown at Dr. Jones' lecture.

*Part of this work was done at Larkhill radio-sonde station.

Since the distance of rain can be measured by radar, it might be thought that here was a valuable means of measuring the height of a cloud base from the ground, a problem of great practical importance for aviation. This, however, is not so, for, since the echo intensity returned by water drops of a given size is inversely proportional to the fourth power of the wave-length of the radiation, cloud droplets, which are of the order of one hundredth of the diameter of raindrops, do not normally give an observable echo even on the highest radio frequencies that can be produced.

T.R.E. have under development a cloud-height meter working on the radar principle but using one-microsecond pulses of visible light produced by a spark. This promises to be a most valuable piece of equipment. If successful, it will have a great advantage over the cloud searchlight in not requiring a base-line.

Another project for the use of pulsed light is the measurement of the density of the upper atmosphere, at heights beyond the reach of radio-sonde balloons, by observation of the energy scattered by the air molecules. This idea is being developed by the Radar Research and Development Establishment, another department of the Ministry of Supply.

Many meteorologists will be on more familiar ground in the last two applications of radar to meteorology discussed by Dr. Jones, namely the measurement of wind and of temperature and humidity in the upper atmosphere. Radar methods of wind measurement are in general use by the Meteorological Office, in conjunction with a radio-sonde working on a wave-length of 11 m. T.R.E. have under development a combined equipment, the radar-sonde theodolite, consisting of an airborne transmitter working on a wave-length of 10 cm., with a radio-theodolite for the measurement of azimuth and elevation, and a recorder for pressure, temperature and humidity, the changing values of which will be signalled by some form of pulse system instead of the sinusoidal modulation in use at present. Range will be measured by an outgoing pulse from the ground on a wave-length of 2 m., which will be picked up by a receiver carried by the balloon, and this in turn will trigger the airborne transmitter and cause it to send a pulse back to the ground. Thus the airborne receiver and transmitter, together known as a responder or transponder, will take the place of the radar reflector now used, which will enable much greater ranges to be obtained. Flight trials have shown that the responder can be followed easily to a range of 100 miles.

An interesting feature of the responder is the thermally insulating container of expanded rubber. This is so effective that during a long flight into the stratosphere at night the heat produced by the battery and circuits is enough to maintain the internal temperature constant within a few degrees. This will have two important results: first, a saving of battery weight, since the performance of the battery falls off rapidly with falling temperature; second, the prospect of an improvement in the accuracy of pressure measurements through the placing of the pressure unit inside the case.

The radio-theodolite will follow the movement of the balloon automatically, and it is hoped that it will also be taught trigonometry and the differential calculus and will present its findings in the form of a record of wind direction and speed synchronised with the record of pressure, temperature and humidity.

In initiating the discussion after the lecture, Sir Robert Watson-Watt recalled the early days of radar, and declared the spirit of its present-day exponents to be worthy of the pioneers. Many others contributed to the discussion with suggestions of needs (chiefly in relation to flying) requiring to be met and of problems awaiting investigation. One speaker made a plea for a simplification of units—feet, yards, miles and metres, Centigrade and Fahrenheit—with which many of us will sympathise.

The lecture has been published in the *Journal of the Royal Aeronautical Society* for May 1949.

D. N. HARRISON

ROYAL METEOROLOGICAL SOCIETY

Waves and swell

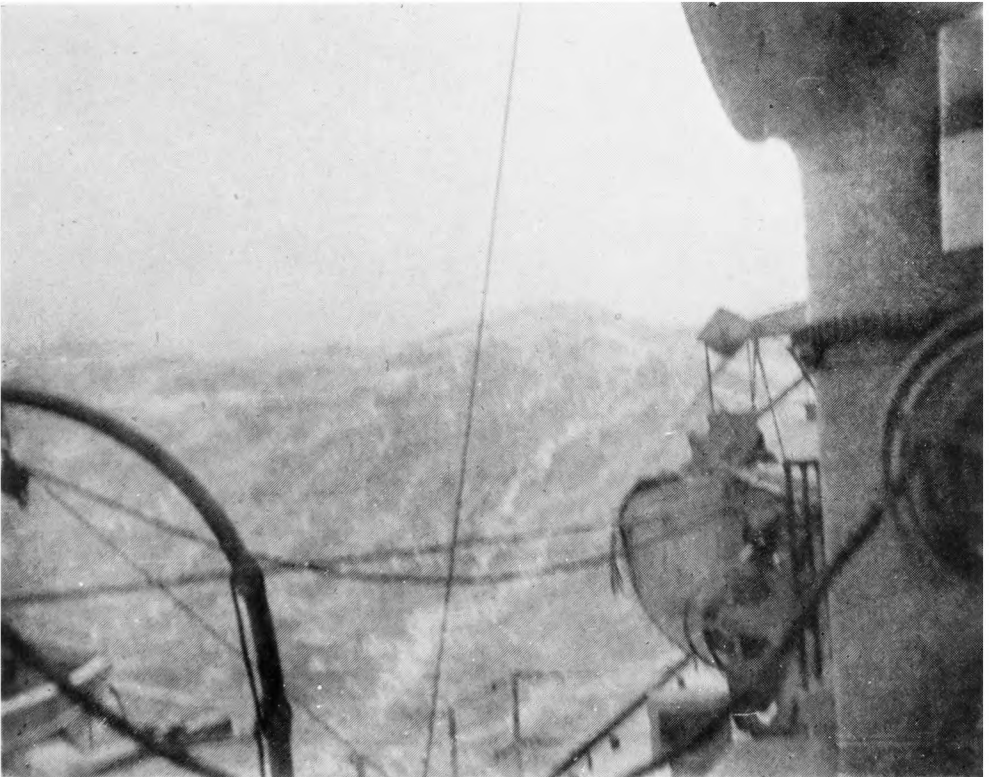
At the meeting of the Society, held at 49 Cromwell Road, on April 20, 1949, Sir Robert Watson-Watt, President, in the Chair, the Symons Memorial Lecture was delivered by Dr. G. E. R. Deacon on the subject "Waves and swell".

Dr. Deacon began his lecture by remarking that interest grew in the subject during the war when it became necessary to forecast the behaviour of landing craft on a beach due to the presence of surf and swell. The bulk of the work was then done under the Director, Naval Meteorological Service, by Inst. Cdr. C. T. Suthons, and is being followed by long-term research.

Until recently waves and swell had been observed almost entirely by visual methods, the main difficulty being the lack of any stationary surface; stereoscopic methods had been used but they were very laborious. Methods now consist of placing a suitable distant-recording instrument on the sea bed in 40–100 ft. of water and measuring either the pressure (which depends on depth of water, period and height of wave) or sound echo between the instrument and the sea surface, thus measuring wave height. A long wave record did not give a simple wave pattern and it was necessary to analyse the record into its component simple waves.

Dr. Deacon showed slides illustrating the instruments in use, including the frequency analyser; he also showed how two wave-trains of almost similar periods combine into groups of waves. With the frequency analyser it is possible to record the individual wave periods electrically and so recognise the long low waves, which could be traced to individual storms far out in the Atlantic. Slides were shown of an analysis of the waves arriving every two hours between March 14 and March 16, 1945, at Peranporth near Lands End. The long waves arrived first becoming progressively shorter; they were traced to a storm near Newfoundland on the 11th and 12th. Another example shown was of long, long-period waves which were observed from May 4 to May 19, 1946; these must have come a distance of 7,000 miles, *i.e.* from the South Atlantic. They also exhibited a periodic frequency change of about $12\frac{1}{2}$ hours showing the effect of the tides.

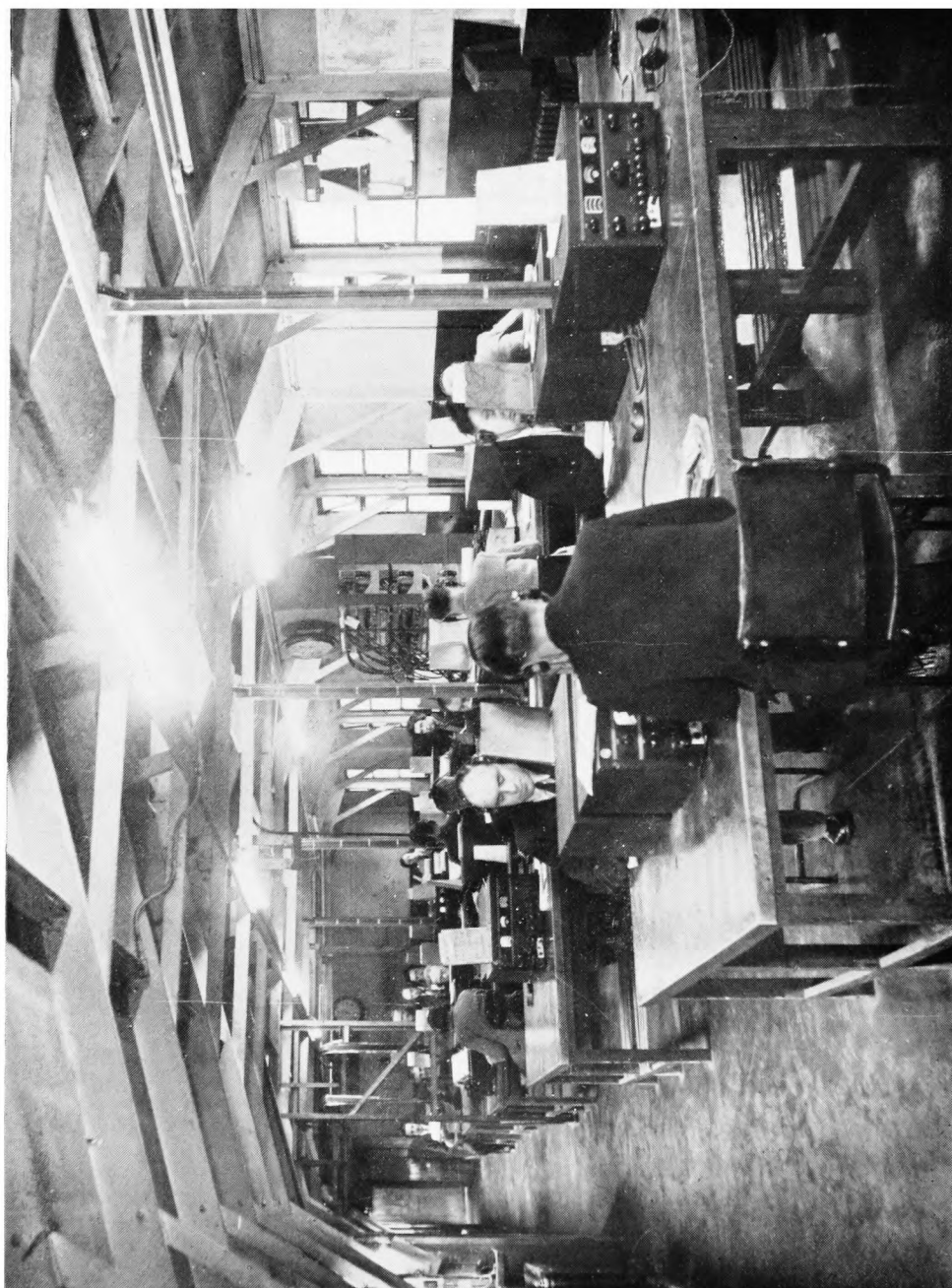
Dr. Deacon went on to discuss the wave characteristics set up by different wind speeds and showed that the smaller-period waves lost energy to the longer-period waves up to a maximum for any given wind speed; this was studied by observation, from aircraft, of waves in the Irish Sea when a steady



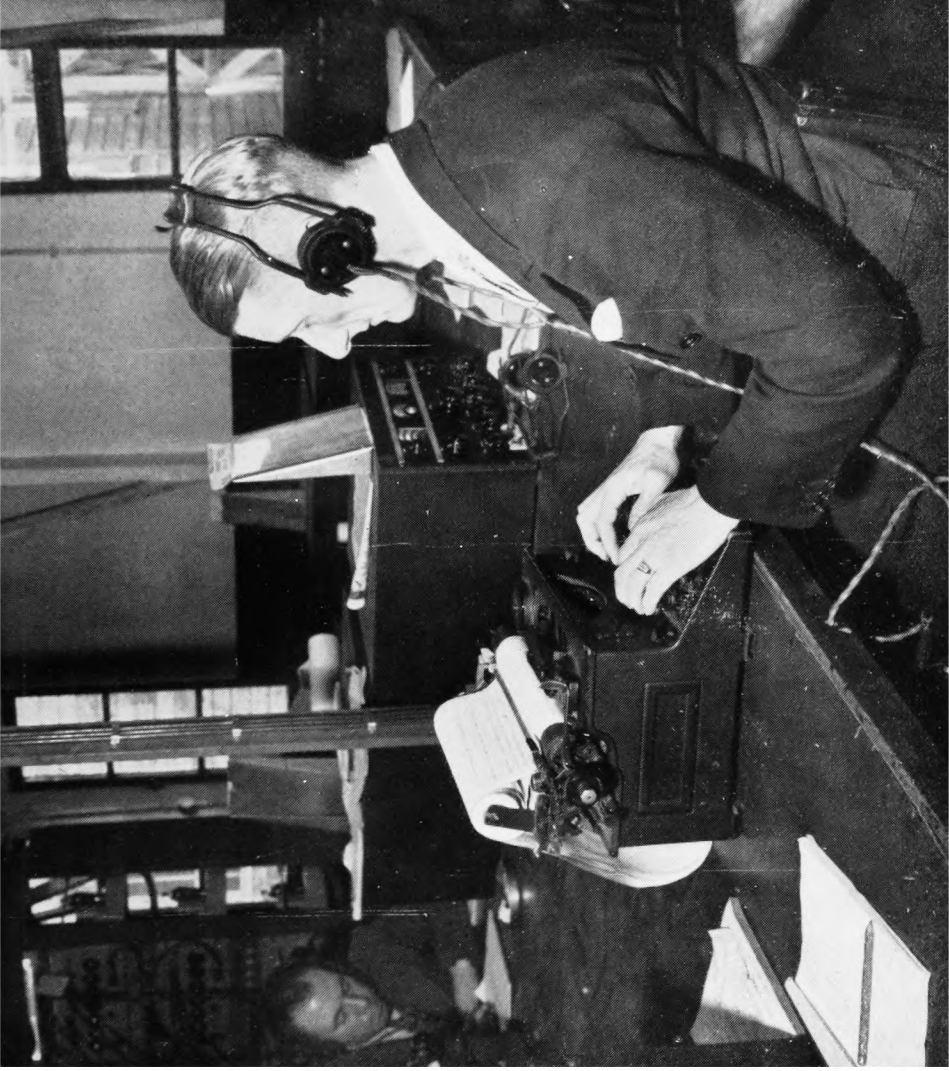
Photographs by Capt. N. F. Israel

STATE OF SEA AT THE CENTRE OF A DEPRESSION

The above photographs were taken aboard O.W.S. *Weather Observer* while on Station j16 ($53^{\circ} 50' \text{N. } 18^{\circ} 40' \text{W.}$) on March 31, 1948. The weather ship was situated near the centre of an intense depression and reported winds of near hurricane force. The upper photograph was taken at about the centre of the depression and gives an impression akin to that of the "eye" of a tropical storm with the typical "pyramidal" sea, the wind having eased temporarily. The lower picture was taken at the height of the storm some little distance from the centre.



GENERAL VIEW OF THE W/T RECEPTION ROOM AT CENTRAL FORECASTING OFFICE, DUNSTABLE,



A W/T OPERATOR TYPING OUT THE MESSAGE AS RECEIVED



SWELL PRECEDING A TROPICAL STORM

This swell was approaching the Bahamas from a West Indian hurricane. Note that the swell waves are long, low and long-crested. The wind is blowing almost at right-angles to the direction of motion of the swell (i.e. parallel to the crests), as is made clear by the breaking of sea waves in the foreground.

26-kt. wind was blowing. He thought it was possible to predict the main details of waves that would reach a coast although it was not possible to predict all the details, the secondary waves being due to wind variations and not a random distribution reaching the coast.

Dr. Deacon discussed, with slides, the effect of shallows, headlands and inlets on waves, showing how the waves tended to bend and become parallel to the coasts, to retard and break with an ebb-tide, to hasten and lengthen with a flood-tide, to alter with irregularities of the sea floor, and to be reflected by steep walls. Waves began to break when the depth of water became less than four thirds of the wave height; the shortening of wave-length and consequent heightening of the long, low, swell waves as they approach a coast was the primary cause of what was known at sea as ground swell. Although the swell would be present out at sea it would be too low and too long to be noticed.

Among meteorological conclusions Dr. Deacon mentioned the approach of long-period waves some 6–12 hours before the approach of a cyclone to Japan, that long waves travelled with gradient wind speed, that the longest wave-period was a measure of the strongest wind, and that the interference of waves of the same period could produce microseismic waves.

At the President's suggestion it was decided to break with the tradition of the Symons Memorial lecture and have a discussion—if Dr. Deacon agreed.

Dr. Slater asked if there was any significance in the ratio of length of waves to their height being normally over 13; because, if it were less than 13, then two waves of almost similar periods would combine to produce waves of ratio less than $6\frac{1}{2}$ which would therefore break.

Inst. Cdr. Suthons remarked that waves broke when the angle at the crest became less than 120° as had been verified in tanks. It depended on each individual wave.

Mr. E. Gold had recently been able to measure wave periods by eye observation only and had timed waves of 14 and 16 sec. on successive days; the swell was of great regularity on the east coast of South America. What was meant by depth of water—mean depth or depth from trough or crest? Dr. Deacon agreed that waves were sufficiently regular for eye observations in the southern hemisphere but it was difficult when a long swell was obscured by a short swell. It was Sverdrup who had found the breaking ratio from many examples using the mean depth.

Mr. T. H. Kirk remarked on the difficulties of observing swell at sea and of the distinction drawn between the state of sea which was caused by the wind and the swell which was caused by waves from a distance. According to an I.M.O. resolution at Washington, observers had been asked to measure the height of swell but it would take many observations to measure the mean swell. We could make climatic charts of swell provided observations were consistent; he would like Dr. Deacon's opinion of the future of observations of swell from ships. Dr. Deacon said the charts, which had proved useful during the war, would be better with new methods of observation. When research had come to the stage of being useful others could carry on with it. Work had been done in the past by the French and New Zealand authorities—the North Atlantic was the place to do research because of the good meteorological network there.

Sir Robert Watson-Watt thought Dr. Deacon was a bit choosy over the scatter of his observations; they were not so scattered as the normal meteorological observations he had had to use.

ROYAL METEOROLOGICAL SOCIETY THE "SIR NAPIER SHAW" COMPETITION

To commemorate the work of Sir Napier Shaw the following prizes are being offered for 1949:—

Junior section.—Age 15 to 21.

1st Prize value £5, 2nd Prize value £3, 3rd Prize value £2.

Subject.—The best description of any weather phenomena actually witnessed at any time by the entrant. The description should be as short as possible and in any case less than 1,000 words in length, and if possible should be illustrated by a sketch or photograph.

Senior section.—Open to any entrant not a professional meteorologist,

1st Prize value £10, 2nd Prize value £5.

Subject.—The best description, photograph, film or drawing (or combination thereof) of any of the following actually witnessed by the entrant:—

Any meteorological phenomena associated with earthquakes or volcanoes.

Any lightning storm or series of lightning storms.

Any cloud phenomena of the rarer sort such as a "Sydney Buster", a "Pampero" or a "Haboob", or sand devils in a desert.

The clouds associated with any tornado or waterspout.

An example of "St. Elmo's Fire".

The effect of any meteorological factor(s) on agriculture, industry or any industrial process, or on any public utility.

The effect of any meteorological factor(s) on plant, insect, or bird life.

Any optical meteorological phenomenon except a rainbow.

Rules

(1) The submission must be in English and, if possible, typed. All drawings and diagrams should be in lead pencil on smooth paper 10 in. × 8 in.

(2) All photographs to be as sharp and as full of gradation as possible, with good contrast. Prints should be glossy and in black and white.

(3) Copyright of submissions gaining prizes to become the property of the Society.

(4) Name and Address to be given in block letters on each entry.

(5) The Society will endeavour to return all unsuccessful work provided a stamped addressed envelope of suitable size is sent.

(6) The Society's decision shall be final and no correspondence can be entertained.

(7) Entries must be addressed to: "Sir Napier Shaw" Competition—Royal Meteorological Society, 49 Cromwell Road, London, S.W.7.

(8) Latest receiving date for the 1949 competition: Home entrants—September 30, 1949; Overseas entrants—October 15, 1949.

(9) Submission of an entry will be deemed to indicate acceptance of these rules. There are no entrance fees and no application forms, but entrants for the Senior Section must include with their entry a certificate that they are not professional meteorologists.

(10) Prizes will be withheld if a sufficiently high standard is not attained.

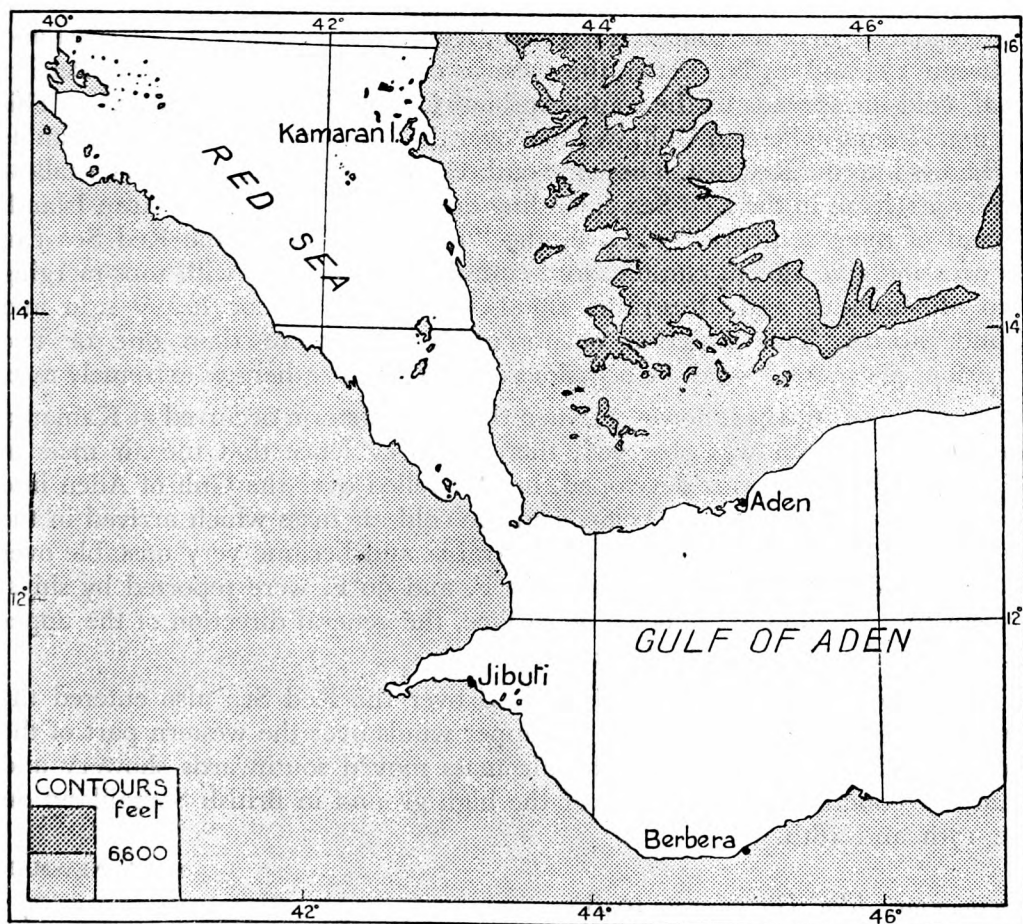
The results of the competition will be announced in *Weather*, the popular monthly magazine published by the Society.

LETTERS TO THE EDITOR

Waterspout seen from Kamaran Island, Red Sea

The following interesting eye-witness account of a waterspout was received from Major D. Thompson, Civil Administrator, Kamaran Island.

He states: "On Saturday, October 16, 1948, at 0800 G.M.T., there were signs in the south-east of an approaching storm. Heavy dark clouds veered towards the island and by 0830 the cloud base over Kamaran Bay at about 1,000 ft. At this time Kamaran itself was not particularly affected. Heavy peals of thunder were heard but there were no vivid flashes of lightning which usually prevail in such storms. By 0845 slight rain fell on Kamaran and the dark clouds began to spread over the southern and centre portions of the island. At 0855, while thunder prevailed, a dull detonation, rather like the sound of gun-fire at a distance, was heard. The sound came from almost due east but slightly south of the island. At first, I considered one of the buildings in the Lazaretto, particularly the water storage tanks which stand on masonry, had collapsed or that one of the 120-ft. wireless masts had fallen down. This impression was gained because of the impact of something very heavy on ground. Immediate examination proved the tanks, masts and other buildings intact. The phenomenon then occurred. Emerging from the clouds at about 1,000 ft. and east of Kamaran, a long trail or spiral of black smoke was seen. The colour could perhaps be more accurately described as 'coal-tar'. The column had a positive downward motion and was cork-screwing, almost in snake-like



fashion, at an angle of roughly 45° and entered the sea in Kamaran Bay 300 yd. east of Kamaran coastline opposite the old Turkish water tower, which is 3 miles north of the Lazaretto. To the naked eye, the column appeared to be about $2\frac{1}{2}$ ft. in diameter right from cloud emergence to point of entry in the sea. At this point the sea was 'boiling' over an area—again to the naked eye—of roughly 35 ft. in diameter. The downward trend of the column continued for fully five minutes when the storm broke over the island. Torrential rain fell, the wind reached gale force (force 7) and the sea became obscured in heavy mist blotting out further observation of the column which had, when last seen, changed colour from black to very dark grey. The storm lasted for an hour and a quarter; slightly over three quarters of an inch of rainfall was recorded.

"As the storm cleared, having swung round from SE. to NE.—almost completing a semicircle—smoke or vapour of the 'coal-tar' colour was observed emerging from the sea at the point already described. It reached a height of about 200 ft. at sea level carried by the wind (or probably propelled by currents in the sea) and gave the impression of a trail of smoke moving northwards at about 25 m.p.h. on the surface of the sea. By 1030 the smoke (or perhaps vapour) had entirely disappeared."

The thunderstorms which developed over the southern Red Sea on October 16, 1948, moved north-westwards to affect the coasts of Eritrea and the Anglo-Egyptian Sudan on October 17 and 18. It is of interest to note that throughout most of the winter period (October to March) there is a "front" or "line of convergence" over the southern Red Sea, lying approximately west to east and between 17° and 14° N. After the passage of a depression down the Persian Gulf, cold air spreads to the south Arabian Coast and then westwards. This air mass from the Persian Gulf, warmed over the Arabian Sea, becomes unstable and flows into the Red Sea. The same outbreak of cold air gives rise to a shallow NW. air stream in the Red Sea extending down to or beyond Kamaran Island. Ascent of the "southern" air over the "northern" air in the Red Sea can on occasion give violent cumulus and cumulonimbus clouds with tops merging into altocumulus and altostratus clouds, and moderate or heavy rain and thunderstorms. This situation occurs rarely—not more than one or two occasions per month—and the occasions of very bad weather are extremely rare.

On October 16, 1948, however, when the thunderstorm occurred at Kamaran and the waterspout was observed, there is no evidence that the air mass in which the thunderstorms developed, had travelled over the Gulf of Aden into the Red Sea. The storm developed in the cold air mass which arrived in the Red Sea from the Persian Gulf across Arabia and became very unstable over the warm sea. Sea temperatures of 93° F. and 90° F. were reported by ships. Except for a shallow layer near the surface, the general direction of the upper winds over the Red Sea was from SE.

The same cold air mass which arrived over the Red Sea also entered the Gulf of Aden from the East, but the upper winds over the western part of the Gulf were from NNE. and as the air mass moved southwards showery and thundery conditions developed over the high ground in British Somaliland on the 17th and 18th.

C. C. NEWMAN

Khormaksar, Aden, December 3, 1948

Description of the synoptic situation

In a note* published in *Nature*, Sir Napier Shaw remarked that the "concentration of attention upon centres of high or low pressure, which are practically points of no motion, instead of upon the air-currents which cause them, is a curious aberration of dynamics."

Now it is not suggested that the modern forecaster concentrates his attention exclusively on the centres of pressure patterns on his synoptic chart. Unlike his predecessor of 30 years ago, who had little or no current upper air data and was therefore largely restricted to thinking two dimensionally, the forecaster of today may have quite an appreciable amount of upper air information for each main synoptic hour, and may thus be able to supplement his surface chart with upper air charts for several levels together with vertical cross-sections; he can, in fact, form a three-dimensional picture of the weather situation.

Nevertheless, phrases mainly related to the surface chart are still used to describe the synoptic situation in very much the same way as they were 30 years ago. A depression and an anticyclone are still referred to as physical entities and mention is often made of the acceleration or retardation of their centres. We know, of course, that the majority of forecasters do not suffer from the "aberration" to which Sir Napier Shaw referred, but, on the other hand, they would probably find it very difficult to describe, three-dimensionally, the changes in the circulation in precise and intelligible language.

In his note Sir Napier Shaw referred to pressure gradient as "the deformation of an isobaric surface from the horizontal by the shifting of air-mass", and, emphasising the enormous release of energy by condensation, he asserted that "the real dynamical agents of the free air are the currents which find their cartographical expression as the straight isobars running between high pressure and low pressure." Maybe, in the course of time, a new phraseology for describing the synoptic situation will be developed and will be related to the position, stability, movement (both horizontally and vertically), and interaction of the air masses involved. In fact, there are already indications of this in the forecast information issued by the Central Forecasting Office.

R. G. VERYARD

MED./M.E., December 4, 1948

[Modern synoptic meteorologists generally think in terms of interrelated variables rather than in terms of cause and effect, unless there is an undoubted time sequence. Three-dimensional treatment is already leading to an expansion of our vocabulary, and this will be developed further. Nevertheless it is likely that depressions and anticyclones will continue to occupy the primary place in our descriptive terminology. They should be regarded as three-dimensional systems of organization of atmospheric motion, with special relation to vertical movement and the associated convergence and divergence. There seems to be no reason for regarding a pressure system as either less or more of a physical entity than an air current or an air mass. All are abstractions, to be used as circumstances require.

Sir Napier Shaw's remarks, quoted by Mr. Veryard, were based more especially on very large air streams which are often associated with straight isobars, which in turn are related to the tendency for high- and low-pressure

*SHAW, SIR NAPIER; Potential temperature and the stratosphere. *Nature, London*, 127, 1931, p. 971.

systems to become elongated or to develop in chain formations. It must be kept in mind that with parallel straight isobars, neglecting the rather obscure effect of latitude variation, a steepening gradient involves ageostrophic motion towards the falling pressure. If these conditions extend to all heights there is no known mechanism for the transference of air from falling to rising pressure. There is now overwhelming evidence that the air transferences, indicated by development in the field of sea-level pressure, are associated with patterns of motion in the upper troposphere different from those in the lower troposphere. If there is a large northerly current at low levels there is normally an upper trough over its eastern half, and similarly there is an upper wedge over the eastern part of a large southerly current.

Sir Napier Shaw emphasised different aspects of these problems at different times. In dealing with questions which must be to some extent speculative (and were more so in his day) it is more important to stimulate thought than to achieve perfect consistency. His work on travelling vortices published in a *Geophysical Memoir** and later in "Manual of Meteorology", Part IV, attracted much interest at the time. Certain types of depression, especially old ones, do at least approximate towards rotating cylinders. Shaw showed that the centre of a moving vortex is separate from the isobaric centre and that the wind centre (*i.e.* the position of the momentary calm) is distinct from both. If the rotation is weak relative to the translation there is no closed isobar or region of calm. In the stronger currents aloft the absence of closed centres is of course more frequent, though the best examples of rotary systems extend to high levels.

The necessities of coding the baratic and prebaratic messages for distribution, and the close relation between the verbal parts of the technical bulletins and the coded parts, may tend towards the over-emphasis of closed sea-level isobars. Mr. Veryard is right to warn us of this danger, but the supreme importance of depressions and anticyclones as organisms remains unaffected.

—C. K. M. DOUGLAS]

Dust devils at Dublin Airport

Dust devils are by no means rare in the subtropical desert regions, but they are extremely rare in the British Isles, and many people were probably surprised to see the report of "present weather = 08" at Dublin Airport on the afternoon of May 12. The report was quite genuine, and the dust devil then seen was only one of several which occurred during the period May 7-13. Most of them, however, were too small to be considered worth reporting.

The dust devils developed on a part of the airfield from which the grass and top soil have been stripped to prepare for the laying of further concrete extensions to the apron and runways. During the previous weeks evaporation considerably exceeded precipitation, so that the ground was very dry. Constant traffic of lorries and excavators had pulverised the exposed surface until it was covered with very fine dust, two to three inches deep in places. This dust layer was very strongly heated by the sun: on the 7th a thermometer laid on the ground, with its bulb just covered by dust, showed 89°F., whereas the temperature a foot above the ground was only 54°F. and the screen maximum that day was only 51°F. !

*SHAW, SIR NAPIER; The travel of circular depressions and tornadoes. *Geophys. Mem., London*, 2, No. 12, 1917.

Most of the devils, which occurred only at irregular intervals, and during the hottest part of the day (1200–1530 G.M.T.) were small whirls up to about ten feet across, and lifting the dust to a height of no more than 50 ft. They showed cyclonic rotation and drifted with the wind until they moved off the dust area on to the grass, when they appeared to collapse, although the dust settled only slowly. I was present at the birth of one small devil, which was first evidenced by a blast of rising hot air and a slight swirl in the dust near by. The swirl grew horizontally rather than vertically and there seemed to be minor eddies circulating round the main centre.

The largest devil observed was at 1340 G.M.T. on the 12th, just as the SE. sea breeze became established after a short calm interval. The dust cloud accompanying a moving lorry suddenly extended in all directions with almost explosive violence. Dust and loose grass were sucked up from an area 20 yd. across. The tufts of grass rose no more than 20 ft., but, in a period of less than a minute, the dust column shot up to a height which some estimated to be as much as 200 ft. By the time the maximum height was reached the base was decaying on the grass.

F. E. DIXON

Dublin Airport, May 18, 1949

NOTES AND NEWS

New type of anemometer

Among the instruments described in Messrs. Nash and Thompson's catalogue is a novel meteorological instrument, the wind velocity vector integrator. This instrument sums on four counters the wind drift in miles and tenths in the four cardinal directions.

The instrument has an anemometer head of the cup type driving a friction wheel mounted with a horizontal axis which, in turn, drives a sphere floating in mercury. The axis of the friction wheel is rotated in a horizontal plane by a wind vane so that the sphere rotates in the vertical plane containing the wind direction at a speed proportional to the wind velocity. Four small friction wheels bearing on the sphere at the cardinal points of its equatorial plane pick up the components of angular velocity of the sphere and actuate a counter by closing contacts.

This instrument attracted much attention when shown at the Physical Society's 1949 exhibition of scientific instruments.

Tellus

We welcome the arrival of the new quarterly journal, *Tellus*, of the Swedish Geophysical Association.

It will contain original contributions in all branches of geophysics and will be edited by Professor C.-G. Rossby.

The first number sets a very high standard. It contains papers by H. Pettersson on the deep ocean bed samples obtained on the recent *Albatross* oceanographic expedition, by T. Bergeron on cloud physics, by E. Palmén on the structure of high level cyclones, by A. Nyberg on an aerological study of large-scale atmospheric disturbances, and C. G. Rossby on the dispersion of planetary waves in a barotropic atmosphere.

Copies of the journal have been ordered for the Meteorological Office Library and the Technical Libraries at Victory House and Dunstable.

REVIEW

Neue Methoden der Wetteranalyse und Wetterprognose, by R. Scherhag. 8vo. 11 $\frac{3}{4}$ in. $\times$ 8 $\frac{1}{4}$ in., pp. xii+424. Springer-Verlag, Berlin/Göttingen/Heidelberg. 1948. Price DM. 80.

This monumental work is the most important book on forecasting to appear since the publication of Petterssen's "Weather analysis and forecasting" and Chromov's "Einführung in die synoptische Wetteranalyse"*. Both these books were published in 1940 and the main difference between Scherhag's book and them is the great increase in the attention paid to upper air analysis.

The author was released early in 1944 from routine forecasting in the German Central Forecast Office to write a book describing the new methods, developed in the Reichsamt für Wetterdienst during the war, to utilise the much increased amount of aerological data. It is a book on weather forecasting, not, as is so often the case, one on thermodynamical and dynamical meteorology with some application to forecasting.

The book is in five parts.

Part I is entitled "Development and bases of synoptic meteorology". As the title implies, it is partly historical but the most important part of it is devoted to methods of constructing contour charts of standard isobaric surfaces and the advantages of such charts. The standard isobaric surfaces used are those for 1000, 500, 225, 96 and 41 mb. and were selected because, over central Europe, the thicknesses between each pair are nearly the same. Part I also contains a short account of dynamical and thermodynamical theory which, in the reviewer's opinion, could have been omitted, as any reader able to use such a book as this would certainly know more than is given in it.

Part II deals with the "General circulation of the troposphere and stratosphere and its effect on weather". The major part of it is concerned with mean contour and thickness charts for the northern hemisphere. Much of the data used for constructing these charts is naturally only for short periods, only months in some cases. The mean contours for the 41-mb. level are particularly interesting with the change from a low between the North Pole and Siberia in January to a high over the same region in July. Much of the data for the Arctic used in compiling these charts was obtained by stations maintained by the Germans for part of the war on Greenland, Spitsbergen and Franz Josef Land. Some indication of the degree of accuracy claimed for the charts and for winds measured from them with the nomogram provided would have been useful. It is by no means clear what data were used in the construction of the charts except over Europe and the parts of the Arctic mentioned above.

Part III entitled "The weather and its analysis" contains detailed analyses of many different types of European weather situations and is probably the most valuable part of the book. Never before have so many synoptic "specimens" been assembled within the covers of one book. In the case of more recent examples the upper air charts are naturally given as well as the surface ones. Older charts have been re-plotted and re-analysed. Cold pools are dealt with for the first time in a text-book with a detailed description of the outstanding one of January-February 1944. Criticisms are that many of the charts are too crowded for legibility, and that a more numerical statement of

*German translation of Russian original, first edition 1934, second edition revised and enlarged, 1937.

air-mass properties might have been provided on the lines of Schinze's 1932 paper on the subject.

Part IV is called "The weather forecast" and is very practical in outlook. A novel feature is a list of meteorological changes difficult to forecast, with instances of forecasts which proved seriously wrong and the reasons why. Much useful advice for the forecaster is given, such as that it is better to issue a forecast on a well analysed earlier chart than to prepare one hastily from data that has just come in. Numerous rules for the application of upper air charts are given together with methods for the preparation of "prebaratic" charts. The part ends with advice on the matters to be considered in forecasting individual elements such as visibility, and on means of estimating the value of a forecast.

Part V is a sketch of long-period forecasting methods. The author regards the synoptic method as useful only up to three days. For longer periods the author thinks that consideration of the kinds of change of weather most likely at particular times of year (singularities), and the study of pressure waves have their uses. The possible effects of sunspots and of volcanic dust are also considered.

An appendix contains tables for finding the heights of the standard-pressure levels, some transformations of units, and a table for finding an approximate value of the 16-Km. wind over Germany from the 11-Km. wind.

The documentation is excellent. There are detailed tables of contents and of illustrations and indexes for both subjects and names. There is a bibliography of 897 items.

The book is certainly one which should be studied by every synoptic meteorologist possessing a moderate knowledge of German.

G. A. BULL

NEWS IN BRIEF

It was announced in the Birthday Honours List, June 1949, that Professor David Brunt, F.R.S., has been created Knight Bachelor by H.M. the King, and that Mr. F. D. Napier, Senior Instrument Maker in the Meteorological Office has been awarded the British Empire Medal.

WEATHER OF MAY 1949

Mean pressure for the month was between 1020 and 1025 mb. over the extreme northern parts of Canada, in the north-east of Greenland, at Spitsbergen, and at Horta, and between 1005 and 1010 mb. over southern Algeria and part of the Sahara. It was nearly normal in North America and two or three millibars below normal over most of central and western Europe.

Broadly speaking, the weather over the British Isles was wet in the southern half of the country and over a part of west Scotland and rather dry on the whole elsewhere. It was sunny in most areas apart from the north-west of Scotland and locally in east England, while the mean temperature was somewhat below the average in the south and rather above the average in the north.

A belt of high pressure extending from the Azores to southern Scandinavia maintained fair weather generally during the first three days of the month;

screen frost occurred locally in England on the 1st, a minimum of 28°F. being recorded at Mildenhall. On the 4th a depression south-west of Iceland moved to the north of Scotland and an associated trough moved south-east over the British Isles, while on the 6th a small depression west of Scotland moved quickly east-south-east. Rain occurred on the 4th and scattered showers on the 5th, while fairly general rain was associated with the depression on the 6th. On the 7th and 8th an anticyclone was situated westward of Ireland; subsequently it moved in over the British Isles where it remained until the 12th and throughout this period fair weather prevailed, with abundant sunshine in most districts. Screen frost occurred again locally in eastern districts on the 8th and 10th; on the latter date 28°F. was recorded at Wittering and 29°F. at Finningley.

A change to unsettled conditions with local thunderstorms occurred on the 14th and persisted for the most part until the end of the month. On the 15th a complex area of low pressure over France and central Europe extended over the British Isles causing local thunderstorms in England. On the 16th a depression approached south-west England from the west and subsequently moved north-east and then north to a position off the north of Scotland by the 19th; general rain and local thunderstorms occurred on the 16th and 17th and scattered rain and a few local thunderstorms on the 18th and 19th. On the 20th a ridge of high pressure developed over the British Isles and later moved slowly east; it was associated with a short fair spell, with good sunshine records in the west and north on the 20th, over most of Britain on the 21st and in eastern districts of Britain on the 22nd. Local thunderstorms occurred, however, in the eastern half of England on the 20th.

Unsettled weather was renewed on the 23rd when a depression off west Scotland moved slowly east-north-east and a small associated secondary moved quickly north-east over southern England giving fairly heavy rainfall in south and east England during the night of the 23rd-24th. On the 27th a depression off north-west Ireland moved irregularly north-north-east and an associated trough moved east over England and Wales; heavy rain fell in Wales and western districts of England, amounting to more than 2 in. at numerous stations (2.93 in. at Machynlleth, Montgomery, 2.77 in. at Rushworth Lodge, West Riding of Yorkshire, 2.69 in. at Hafod Fawr, Merioneth, and 2.64 in. at Rochdale, Lancashire). In the closing days an almost stationary depression was situated off the west of Scotland; weather was showery with local thunderstorms but long, sunny periods.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERTAURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	77	27	—0.4	112	—1	119	46
Scotland ..	75	24	+ 0.7	90	—1	112	38
Northern Ireland ..	72	32	0	90	0	117	42

RAINFALL OF MAY 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	1·91	109	<i>Glam.</i>	Cardiff, Penylan ..	3·71	151
<i>Kent</i>	Folkestone, Cherry Gdn.	2·11	126	<i>Pemb.</i>	St. Ann's Head ..	2·18	108
	Edenbridge, Falconhurst	1·75	94	<i>Card.</i>	Aberystwyth ..	2·78	134
<i>Sussex</i>	Compton, Compton Ho.	2·34	105	<i>Radnor</i>	Tyrmynydd ..	5·91	172
	Worthing, Beach Ho.Pk.	1·45	88	<i>Mont.</i>	Lake Vyrnwy ..	4·67	138
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	1·33	78	<i>Mer.</i>	Blaenau Festiniog ..	6·40	113
	Bournemouth ..	1·68	96	<i>Carn.</i>	Llandudno ..	1·87	105
	Sherborne St. John ..	2·79	144	<i>Angl.</i>	Llanerchymedd ..	1·77	75
<i>Herts.</i>	Royston, Therfield Rec.	2·24	115	<i>I. Man.</i>	Douglas, Borough Cem.	·92	37
<i>Bucks.</i>	Slough, Upton ..	2·32	138	<i>Wigtown</i>	Port William, Monreith	·84	36
<i>Oxford</i>	Oxford, Radcliffe ..	2·41	129	<i>Dumf.</i>	Dumfries, Crichton R.I.	1·88	68
<i>N'hant.</i>	Wellingboro', Swanspool	2·95	152		Eskdalemuir Obsy. ..	3·28	99
<i>Essex</i>	Shoeburyness ..	1·79	138	<i>Roxb.</i>	Kelso, Floors ..	1·35	70
<i>Suffolk</i>	Campsea Ashe, High Ho.	1·94	129	<i>Peebles</i>	Stobo Castle ..	2·33	103
	Lowestoft Sec. School ..	1·67	104	<i>Berwick</i>	Marchmont House ..	1·83	74
	Bury St. Ed., Westley H.	2·19	120	<i>E. Loth.</i>	North Berwick Res. ..	1·90	95
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·72	149	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	1·90	93
<i>Wilts.</i>	Bishops Cannings ..	2·63	135	<i>Lanark</i>	Hamilton W. W., T'nhill	1·79	75
<i>Dorset</i>	Creech Grange ..	2·47	121	<i>Ayr</i>	Colmonell, Knockdolian	1·71	67
	Beaminster, East St. ..	3·69	179		Glen Afton, Ayr San ..	2·16	72
<i>Devon</i>	Teignmouth, Den Gdns.	2·18	119	<i>Bute</i>	Rothsay, Ardenraig	2·93	97
	Cullompton ..	2·71	125	<i>Argyll</i>	L. Sunart, Glenborrodale	3·42	96
	Barnstaple, N. Dev. Ath.	2·36	114		Poltalloch ..	3·32	115
	Okehampton, Uplands	3·08	115		Inverary Castle ..	3·83	97
<i>Cornwall</i>	Bude School House ..	2·21	120		Islay, Eallabus ..	1·63	62
	Penzance, Morrab Gdns.	2·75	124		Tiree ..	2·06	82
	St. Austell, Trevarna ..	3·17	131	<i>Kinross</i>	Loch Leven Sluice ..	2·34	96
	Scilly, Tresco Abbey ..	2·91	132	<i>Fife</i>	Leuchars Airfield ..	1·37	70
<i>Glos.</i>	Cirencester ..	2·83	137	<i>Perth</i>	Loch Dhu ..	3·47	77
<i>Salop.</i>	Church Stretton ..	3·23	127		Crieff, Strathearn Hyd.	2·58	104
	Cheswardine Hall ..	2·36	107	<i>Perth</i>	Pitlochry, Fincastle ..	2·64	125
<i>Worcs.</i>	Malvern, Free Library	2·42	112	<i>Angus</i>	Montrose, Sunnyside ..	1·51	74
<i>Warwick</i>	Birmingham, Edgbaston	2·21	103	<i>Aberd.</i>	Braemar ..	1·79	75
<i>Leics.</i>	Thornton Reservoir ..	2·61	130		Dyce, Craibstone ..	1·88	74
<i>Lincs.</i>	Boston, Skirbeck ..	1·92	109		Fyvie Castle ..	2·22	86
	Skegness, Marine Gdns.	1·62	95	<i>Moray</i>	Gordon Castle ..	2·03	96
<i>Notts.</i>	Mansfield, Carr Bank ..	2·36	111	<i>Nairn</i>	Nairn, Achareidh ..	1·75	98
<i>Derby</i>	Buxton, Terrace Slopes	3·15	102	<i>Inv's</i>	Loch Ness, Foyers ..	2·18	89
<i>Ches.</i>	Bidston Observatory ..	2·86	151		Glenquoich ..	4·73	86
<i>Lancs.</i>	Manchester, Whit. Park	3·47	164		Fort William, Teviot ..	4·05	103
	Stonyhurst College ..	2·46	86		Skye, Duntuiln ..	4·55	160
	Blackpool ..	2·68	123	<i>R. & C.</i>	Ullapool ..	1·96	80
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·66	84		Applecross Gardens ..	4·09	127
	Hull, Pearson Park ..	1·18	61		Achnashellach ..	3·63	86
	Felixkirk, Mt. St. John	1·34	71		Stornoway Airfield ..	2·50	103
	York Museum ..	1·80	90	<i>Suth.</i>	Laig ..	·	·
	Scarborough ..	1·80	94		Loch More, Achfary ..	4·91	112
	Middlesbrough ..	·89	46	<i>Caith.</i>	Wick Airfield ..	1·98	96
	Baldersdale, Hury Res.	1·44	56	<i>Shetland</i>	Lerwick Observatory ..	1·39	67
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	·54	27	<i>Ferm.</i>	Crom Castle ..	2·29	82
	Bellingham, High Green	1·10	46	<i>Armagh</i>	Armagh Observatory ..	1·79	75
	Lilburn Tower Gdns. ..	1·27	55	<i>Down</i>	Seaforde ..	1·75	67
<i>Cumb.</i>	Geltsdale ..	1·37	53	<i>Antrim</i>	Aldergrove Airfield ..	1·85	81
	Keswick, High Hill ..	2·84	89		Ballymena, Harryville ..	2·31	81
	Ravenglass, The Grove	2·81	100	<i>L'derry</i>	Garvagh, Moneydig ..	2·04	80
<i>Mon.</i>	Abergavenny Larchfield	2·30	86		Londonderry, Creggan	3·33	127
<i>Glam.</i>	Ystalyfera, Wern House	4·67	134	<i>Tyrone</i>	Omagh, Edenfel ..	3·28	127

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, JANUARY 1949

STATIONS	PRESSURE			TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN cLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE		
	Mean of day M.S.L.	Diff. from normal	mb.	Absolute		Mean values						Total	Diff. from normal	Days	Daily Mean	Per- centage of possible	
				Max.	Min.	Max.	Min.	1 2	Max. and Min.								Diff. from normal
										°F.	°F.						
London, Kew Observatory	1022.3	53	+5.4	28	47.1	37.4	42.3	+1.8	40.0	6.7	1.20	-0.56	12	1.8	21		
Gibraltar	1022.9	66	+1.4	44	60.1	50.9	55.5	+0.6	51.0	4.6	2.32	—	7	5.3	54		
Malta	1019.3	65	+2.3	41	59.3	49.2	54.3	-1.0	53.1	4.5	2.28	—	18	6.3	64		
St. Helena	1014.1	78	-0.9	59	71.5	60.2	65.9	+2.2	60.9	7.7	0.33	-1.90	9	—	—		
Lungi, Sierra Leone	1010.9	92	—	63	87.8	69.9	78.9	—	71.3	3.4	0.00	—	0	—	—		
Lagos, Nigeria	1010.1	96	+0.4	66	91.8	70.7	81.3	+0.4	76.1	5.4	0.00	—	0	5.7	49		
Kaduna, Nigeria	1010.0	97	—	55	89.0	58.6	73.8	+0.2	55.1	1.5	0.00	0.00	0	9.1	79		
Chileka, Nyasaland	1009.9	98	-1.6	63	90.4	69.9	80.1	+5.0	69.4	3.7	1.20	-7.39	7	7.6	59		
Lusaka, Rhodesia	1008.7	95	-1.0	61	86.4	64.3	75.3	+4.6	65.2	5.8	3.00	-7.35	14	8.9	69		
Salisbury, Rhodesia..	1009.9	90	-0.9	54	81.8	60.7	71.3	+2.3	62.6	4.5	6.02	-1.69	14	8.2	63		
Cape Town	1012.8	87	-0.6	52	79.4	62.6	71.0	+1.1	60.4	2.5	6.02	+5.34	4	—	—		
Palmietfontein, S. Africa	1010.6	94	—	49	82.3	60.6	71.5	—	61.0	5.0	8.12	—	20	8.1	—		
Mauritius	1015.4	85	-0.4	51	81.1	57.7	69.4	+2.8	59.7	0.8	0.05	-0.37	1	9.2	84		
Calcutta, Alipore Obsy.	1013.1	91	-0.5	65	86.3	68.8	77.5	+2.0	65.8	1.7	0.00	-0.10	0	9.0	81		
Bombay	1014.4	86	+0.3	64	83.4	67.2	75.3	-0.9	67.8	2.9	0.00	-1.14	0	10.0	88		
Madras	1011.5	90	+0.7	66	87.2	71.9	79.5	0.0	71.3	4.7	1.50	-1.75	7	7.7	65		
Colombo, Ceylon	1011.3	92	+0.9	71	87.8	74.1	80.9	+1.2	74.6	5.4	7.91	-1.98	10	—	—		
Singapore	1021.8	75	+2.1	43	64.9	54.0	59.5	-0.7	53.3	—	0.08	-1.24	3	6.5	60		
Hongkong	1012.6	93	+0.2	51	75.1	62.6	68.9	-2.7	63.7	5.0	10.80	+7.13	14	7.8	55		
Sydney, N.S.W.	1013.2	100	+0.3	49	76.9	56.9	66.9	-0.5	58.4	4.7	1.34	-0.55	11	8.1	56		
Melbourne	1014.4	100	+1.4	51	81.6	58.7	70.1	-3.6	58.9	4.0	0.24	-0.48	5	9.3	67		
Adelaide	1012.7	104	+0.2	55	87.5	65.6	76.5	+2.7	65.1	4.0	0.20	-0.14	5	9.0	64		
Perth, W. Australia	1012.8	108	+1.4	53	90.2	63.4	76.8	-0.6	59.1	3.2	0.00	-0.46	0	—	—		
Coalgardie	1011.7	95	+0.4	64	84.3	67.9	76.1	-1.1	67.7	4.2	5.17	-1.28	8	9.5	69		
Brisbane	1012.3	86	+2.0	41	67.5	50.6	59.1	-2.9	54.0	6.2	4.20	+2.37	11	6.4	43		
Hobart, Tasmania	1008.5	76	-3.6	44	66.5	52.3	59.4	-1.8	56.0	5.8	2.25	-1.08	13	6.3	43		
Wellington, N.Z.	1007.4	93	-0.1	71	85.8	74.5	80.1	+0.2	76.6	5.9	21.38	+9.95	22	6.0	46		
Suva, Fiji	1008.5	89	+1.0	71	86.9	74.5	80.7	+0.6	78.5	4.6	11.82	-5.94	16	7.9	62		
Apia, Samoa	1016.1	91	+1.0	65	84.8	67.0	75.9	-0.9	70.7	1.9	0.02	-0.94	1	8.6	77		
Kingston, Jamaica	—	91	—	69	86	71	78.5	+1.4	71	3.5	0.71	-3.67	14	—	—		
Grenada, W. Indies	1020.1	52	+2.2	9	35.0	23.3	29.1	+6.9	26.5	7.0	3.33	+0.54	14	1.5	16		
Toronto	1023.6	40	+2.7	—	7.3	—	-1.9	+2.0	-3.8	4.3	2.04	+1.13	10	3.3	38		
Winnipeg	1020.5	50	+5.0	—	32.3	15.8	24.1	+4.9	19.4	5.3	5.71	+0.91	15	3.4	37		
St. John, N.B.	1026.9	50	+10.9	12	24.2	37.5	30.9	-8.1	28.1	5.2	0.89	-3.65	11	3.8	43		
Victoria, B.C.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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INTERNATIONAL METEOROLOGICAL ORGANIZATION Second Telecommunications Sub-Commission Meeting, Stockholm, April 1949

By C. V. OCKENDEN, B.Sc.

The second meeting of the I.M.O. European Regional Sub-Commission for the Transmission of Weather Information was held at Stockholm from April 20 to May 4 and was attended by delegates from seventeen countries. The Conference took place in the Swedish Meteorological Institute under the presidency of Dr. Bjorkdal in the absence of Dr. Ångström who was attending the Second Conference of the International Civil Aviation Organization (I.C.A.O.) North Atlantic Ocean Stations in London. As at the first meeting which was held in London in May 1948* the questions discussed fell naturally under two main headings—the collection and dissemination of data within Europe by W/T and by teleprinter. Mr. Rafalowski (Poland) and Mr. Ockenden (United Kingdom) were elected Chairmen of sub-committees to study Agenda items which fell under these two headings.

The Scandinavian countries are now making considerable use of teleprinter land-lines, and a plan was evolved which will provide Denmark, Norway and Sweden with as much as possible of the international meteorological data, including North American data, which are broadcast by the four main teleprinter centres, Dunstable, Paris, Frankfurt and B.A.F.O. The circuits envisaged will also provide a "ring system" for the exchange of data between the Scandinavian countries themselves and will ultimately permit observations from Finland, as well as collectives from Oslo, Stockholm and Copenhagen, being fed into the international network.

Switzerland and Italy now have land-line teleprinter connexions to the international meteorological network, and the Conference felt that the time had come to start considering a long-term plan for the whole network which until now has been based largely upon requirements as they developed during the concluding phases of the war. It is hoped that by 1951 it will be possible to install regenerative repeaters wherever they may be necessary, which will enable longer circuits with more links to be used. It may also be possible to work with only three main telecommunication centres in western Europe.

* *Met. Mag.*, London, 77, 1948, p. 220.

At an I.C.A.O. North Atlantic Meteorological Telecommunications meeting which was held in London immediately before the Stockholm Conference, it was decided that Paris should be the main European terminal for the exchange of American and European information by radio teleprinter. The I.M.O. Conference at Stockholm decided to accept this recommendation as the basis of the I.M.O. European telecommunications scheme. Plans were therefore made for the re-allocation of areas of responsibility among the four main teleprinter centres so as to allow Paris sufficient time to re-diffuse bulletins originated at New York. Important consequences of the London decision are that the Montreal-Prestwick meteorological W/T channel which was established in 1940 for war-time purposes will cease on December 1, 1949, and on October 1, 1949, the British W/T broadcasts on transmitter GFT will be replaced by a French broadcast designed to relay North American data to those European countries which do not receive this material by teleprinter.

The sub-committee charged with the task of planning the reorganization of W/T broadcasts soon became aware of a general demand for the speedier re-issue of "A" station data by the four "sub-continental" transmitters: Dunstable, Paris, Rome and Moscow. There was an almost equally urgent demand for a transmission which would contain only aerological information. It was felt that the increased amount of radio-sonde and upper wind data which have become available since the war make it necessary for a broadcast to be made from one European centre on the same lines as the pre-war broadcast from a German transmitter.

Regarding national W/T broadcasts it was suggested that, in order to affect economy in frequencies and to facilitate the collection of data at the sub-continental centres, broadcasts from some of the smaller countries could be combined and made from one transmitter. The views of those countries which were not represented at the Conference are being obtained.

Both sub-committees were of opinion that an abbreviated system for the heading of meteorological bulletins should be introduced; the abbreviations which have been in use for some time on certain circuits were considered suitable, but it was felt that any such system should not be introduced in any one region before it had been approved for world-wide use by the I.M.O.

In all, 39 recommendations were made, covering such points as teleprinter operational procedure, the exchange of terminal forecasts on the meteorological teleprinter network, the installation of a W/T broadcast transmitter in the Faeroes and the addition of "Block Indicator" numbers at the end of collective messages.

Many European countries, including Great Britain, are interested in the development of facsimile apparatus for the transmission of weather maps. Delegates were able to compare notes on the progress made in the experimental work going on in France, the Netherlands, the United Kingdom and Sweden. A sub-panel was formed to draft a specification for facsimile apparatus which would satisfy the requirements of meteorologists, and decided to adopt, as a working basis, a chart size of 40 cm. $\times$ 50 cm. and a definition such that figures 1 mm. high would be clearly legible. It was considered that the "scanning density" would have to be not less than $5\frac{1}{2}$ lines per millimetre, and that the time required for transmission should not exceed 20-25 min.

Delegates were invited to join a Sunday excursion to the Royal Palace at Drottningholm and to attend a dinner given by the Swedish Ministry of Communications. Both these events gave full evidence of the traditional Swedish hospitality.

INTERNATIONAL CIVIL AVIATION ORGANIZATION

Second Conference of I.C.A.O. North Atlantic Ocean Stations, London, 1949

By Cdr. C. E. N. FRANKCOM, O.B.E., R.N.R.

The I.C.A.O. Conference on ocean weather ships, which opened in London on April 20, 1949, was attended by representatives of Belgium, Canada, Denmark, France, Iceland, Ireland, Mexico, Netherlands, Norway, Portugal, Sweden, the United Kingdom, the United States of America and the International Meteorological Organization. Brigadier Booth of Canada was elected Chairman.

The object of the Conference was to consider the ocean weather station plan, which had been originally set up by the 1946 Conference, to see if it would be practicable to reduce the number of stations, and to consider any possible improvements or modifications to the scheme.

One of the most important questions before the Conference was the sharing of financial responsibility amongst the countries concerned. It proved impracticable to assess non-aeronautical benefits and it was finally decided to share the cost on the basis of the number of scheduled flights across the Atlantic of aircraft belonging to each nation.

The possibility of reducing the number of ships on account of the heavy cost in money and manpower was considered, and though the previous number of 13 was regarded as really desirable meteorologically, it was agreed to reduce the number to 10 as the absolute minimum, below which the ships would be too widely spaced.

As a result of the agreed re-allocation of responsibility and of the reduction of stations, the new stations will be operated as follows:—

Station	Position	Governments responsible	Number of vessels
A	62° 00'N. 33° 00'W.	{ Netherlands United States	1 2
B	56° 30'N. 51° 00'W.	{ Canada United States	1 2
C	52° 45'N. 35° 30'W.	United States	3
D.	44° 00'N. 41° 00'W.	United States	2½
E	35° 00'N. 48° 00'W.	United States	2½
H	36° 00'N. 70° 00'W.	United States	2
I	59° 00'N. 19° 00'W.	United Kingdom	2
J	52° 30'N. 20° 00'W.	United Kingdom	2
K	45° 00'N. 16° 00'W.	France	2
M	66° 00'N. 02° 00'E.	Norway in co-operation with Sweden, Belgium and Denmark.	2

} Netherlands to perform
7 patrols annually.

It will be noted that the former stations G (U.S.A.) and L (France) disappear, and stations E and F (U.S.A.) are amalgamated into one station E (U.S.A.). France moves from station L to K. Belgium withdraws her ship, which formerly operated at K, from service and becomes a cash contributor instead. Netherlands moves her one ship from K to assist in operating station A (with U.S.A.) and provides another ship for part-time operation at J and K (with U.K. and France). The old and new networks are shown on the map at Fig. 1.

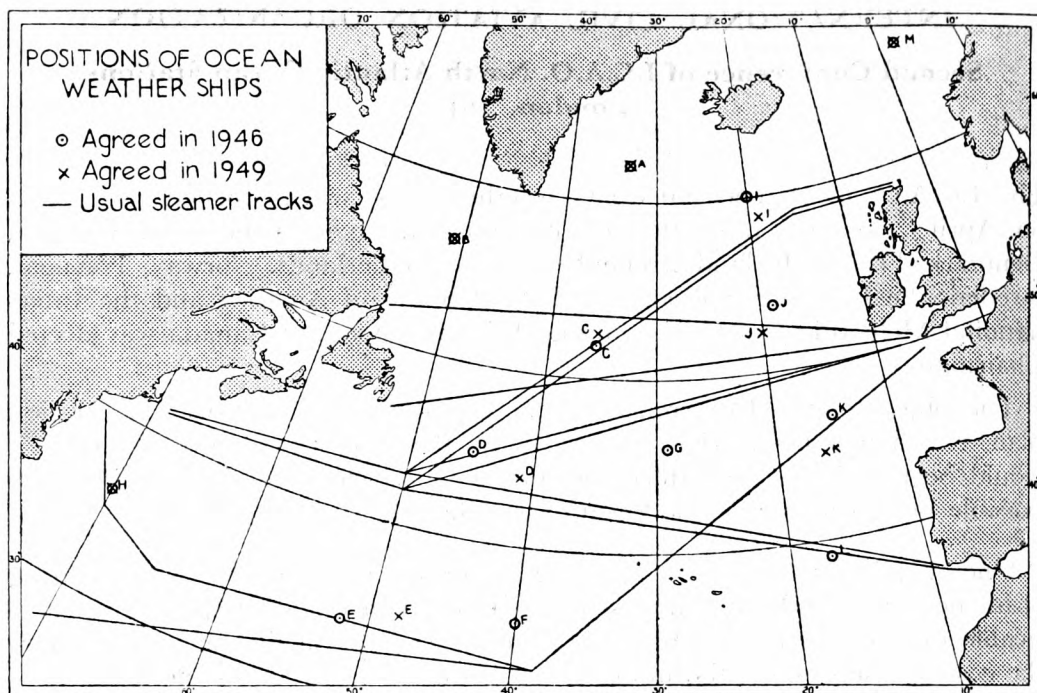


FIG. 1—OLD AND NEW OCEAN WEATHER STATIONS IN THE NORTH ATLANTIC

The net result of this Agreement, as far as the United Kingdom is concerned, is that the four British ocean weather ships will continue to operate at the new stations I and J, but that they will be relieved from this duty for five voyages during the year, which will mean a very considerable economy in the matter of fuel, meteorological stores and repairs. Great Britain is also relieved of her responsibility of contributing towards the joint operation of Station M.

No notable changes were made in the functions to be performed by the ships except that those of other countries are to be encouraged to increase the frequency of radio-sonde ascents from two to the four already performed by British ships.

A new Agreement on the organization, to last until June 30, 1952, was signed on May 6, 1949, and will come into force when accepted by the governments responsible for operating not less than eighteen of the ships concerned.

All the delegates at the Conference, though naturally concerned to administer the organization as economically as possible, showed their appreciation of the value of the weather ships as regards both meteorological observations and immediate navigational aid to aircraft.

NOTES ON SYNOPTIC WEATHER ANALYSIS ON THE FRINGE OF ANTARCTICA

By G. DE Q. ROBIN, M.Sc.

Manning the Antarctic bases of the Falkland Islands Dependencies Survey (F.I.D.S.) is a cold and lonely task which was first commenced in January 1944. That year, bases were established at the old whaling-factory site on Deception Island and at Port Lockroy. Gradual expansion of the Survey has taken place since then. Hope Bay ($63^{\circ}24'S$, $56^{\circ}59'W$.) was established in 1945 and Cape

Geddes ($60^{\circ}42'S. 44^{\circ}35'W.$) and Stonnington Island, Marguerite Bay ($68^{\circ}11'S. 67^{\circ}01'W.$), in 1946. In 1947 the Port Lockroy base was transferred to the site of the 1934-37 British Graham Land Expedition's base in the Argentine Islets, and the South Orkney's base was moved from Cape Geddes to Signy Island ($60^{\circ}43'S. 45^{\circ}35'W.$).

One of the main functions of these bases is the taking and transmission of weather observations throughout the year. Using them in combination with weather reports from South America, Falkland Islands, South Georgia and occasional ship reports, it is now possible to study the weather on this fringe of Antarctica by synoptic charts. This gives a different and most useful approach to antarctic weather studies, compared with past antarctic expeditions whose work has been largely climatological.

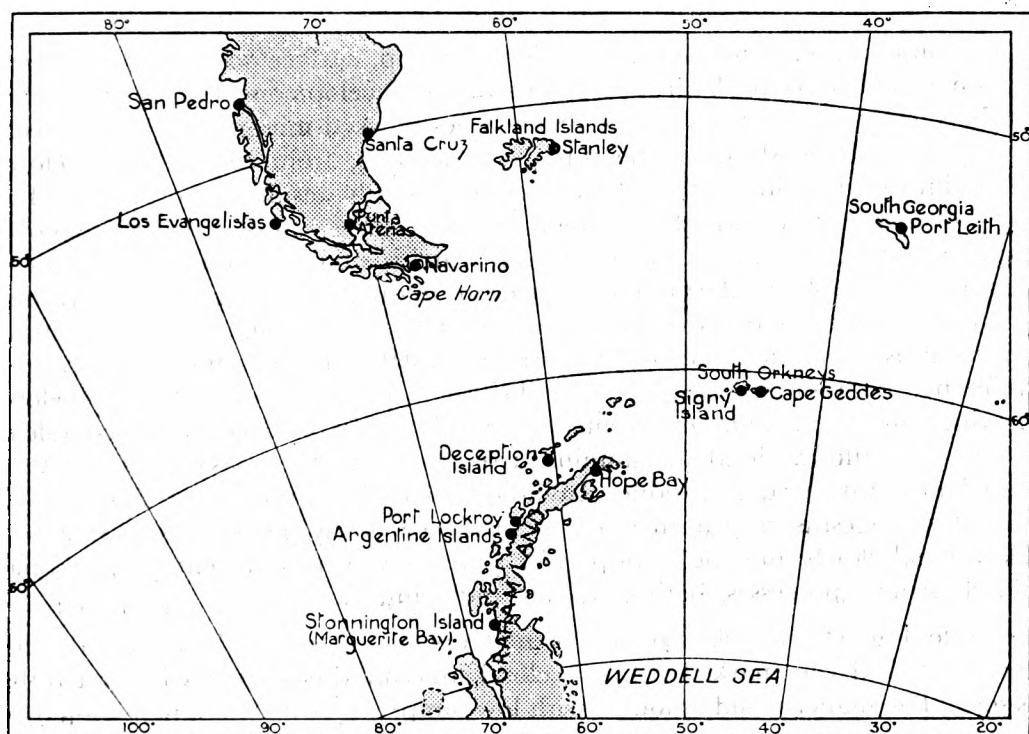


FIG. 1—STATIONS IN SOUTH AMERICA AND THE FALKLAND ISLANDS DEPENDENCIES SURVEY

Lamb* employed these (F.I.D.S.) reports in preparing weather maps of the antarctic seas, during the southern summer of 1946-47, for the benefit of ships and aircraft of a whaling company in the Antarctic over 2,000 miles further east. He was able to do this because theories and methods used in northern-hemisphere forecasting were found to apply particularly well in the Southern Ocean. As his work was confined to summer and autumn months, I have thought it worth while to add some notes on the weather systems I noted more particularly during the winter and spring of 1947 at the South Orkneys. Frontal-depression theories are also found to apply extremely well during the winter months as can readily be seen from the instrumental traces reproduced.

*LAMB, H. H.; A meteorologist in the Antarctic. *Met. Mag., London*, **76**, 1947, pp. 231 and 247.

The principal air masses experienced around the edge of the antarctic continent are

Antarctic air (A) being that air mass which has spent some time over the continental and barrier ice of Antarctica.

Polar maritime air (Pm) being the air normally found in the southern half of the westerly wind belt of the southern hemisphere.

A more temperate type of maritime air (Tm) was also occasionally experienced, this air coming from a more northerly portion of the westerly wind belt.

Due to the oceanic situation of the South Orkneys, radiation appears to have only a small effect on weather phenomena. It is thus possible to divide the types of weather experienced there, apart from cyclonic disturbances, into four main groups according to the type of air mass present (A or Pm), and to the underlying surface—open water or pack ice.

In winter, when pack ice surrounds the group, surface cooling has the predominant effect. With A air, this results in the development of inversions close to the surface and a cloudless sky. Sometimes marked mirage effects were seen to separate steep islets, or the top of an iceberg, from the horizon below. With Pm air in winter, the surface cooling usually results in formation of a layer of stratiform cloud. In summer, the sea temperature rarely rises above freezing point, and the effect on Pm air remains similar, surface cooling producing a layer of stratiform cloud, or, quite frequently, of fog. However, any A air reaching the group over the open sea undergoes heating, and the resulting effects must vary according to the time available for heating, temperature difference between sea and air, and the stability conditions in the air before heating. Actually, clouds experienced with this air mass varied from a complete layer of stratiform cloud to cumulus congestus. On no occasion was heating sufficiently advanced to produce anvil-cirrus clouds or thunder, but clouds of cumulus-congestus appearance often produced fairly heavy snow showers. Occasional slowly moving anticyclones were, however, sufficient to overcome cloud-forming processes, both in winter and summer.

Table I gives the relation of screen temperature to cloud amount during the year, and the marked drop in cloud amount during the winter months is seen. The higher cloud amounts with low temperature in May and September are due to open water surrounding the group during part of these months. A more striking result of the above effects was that, during 1947, the largest monthly hours of sunshine were recorded in August (southern winter) and the minimum number in February (southern summer). Arctic sea smoke was observed only once, shortly before the arrival of the pack ice in May. The vapour-pressure difference between sea and air was then 4.5 mb. Local orographic effects were quite frequent, but as they are not of great general interest I shall not discuss them, except to mention that they account satisfactorily for the glaciation of Signy Island, on which our station was situated, being much less than that of the higher and larger Coronation Island just to the north.

In autumn, winter, and spring, sharp frontal surfaces resulting in cyclonic development frequently form between A and Pm air, that is, along the antarctic front. The natural place for such fronts to develop most strongly is along the edge of the pack ice, which in winter runs roughly in an east-north-east direction across the South Atlantic. Cyclones observed in the antarctic front

were either well developed cyclones which approached Graham Land and from the west, or were young cyclones which formed near the northern tip of Graham Land, the latter being more in evidence in late autumn and spring. The direction of travel of these cyclones is roughly eastwards, and appears to depend mainly on the direction and latitude of the pack-ice edge. This construction fits winter synoptic charts much better than the possibly better-known hypothesis, that the cyclonic centres travel south-eastwards towards the semi-permanent Weddell Sea low, in which they are finally absorbed. The speed of travel of both young and old cyclones is around 600 miles per day, a somewhat higher figure than in temperate latitudes. Both types often occur in a train of two or three successive cyclones, and a train of well developed cyclones is generally a forerunner of the injection of a cold air mass over the South American continent. These air masses are then protected on the west by the Andes, and travel northwards as far as Brazil with typical cold-front weather.

TABLE I—RELATION OF TEMPERATURE TO CLOUD AMOUNT, SOUTH ORKNEYS, 1947

Station and period	Temperature ranges									
	less than 0 °F		0–10°F.		10–20°F.		20–30°F.		over 30°F.	
	No. of obs.	Mean cloud	No. of obs.	Mean cloud	No. of obs.	Mean cloud	No. of obs.	Mean cloud	No. of obs.	Mean cloud
	tenths		tenths		tenths		tenths		tenths	
Cape Geddes										
January 10–31 ..	..	..	..	..	..	..	26	9.0	39	9.2
February ..	..	..	..	..	..	..	18	9.5	66	9.9
March 1–14 ..	..	..	..	..	..	..	6	10.0	33	8.8
Signy Island										
March 22–31 ..	..	..	..	..	..	..	6	9.1	22	8.1
April ..	..	..	..	..	3	10	35	9.3	54	8.2
May ..	8	8.4	8	8.4	23	8.0	40	8.9	11	9.0
June ..	11	5.3	25	7.2	20	8.1	26	9.2	9	10
July ..	27	3.2	12	5.2	12	6.5	17	8.9	25	9.2
August ..	13	3.0	22	5.6	6	4.0	31	7.7	21	8.8
September ..	3	6.7	4	7.2	15	9.5	35	8.6	33	8.7
October ..	..	..	..	..	11	9.0	30	8.1	52	8.1
November ..	..	..	..	..	..	..	22	8.5	68	9.4
December ..	..	..	..	..	..	..	60	9.2	33	9.1
Total ..	62	4.4	71	6.5	90	8.0	350	8.8	485	8.9

Figs. 2–8 illustrate a well developed antarctic-front cyclone in August 1947 which, combined with the situation of the subtropical anticyclone well south over South America, caused one of the famous winter gales “south of the Horn”, with a pressure gradient of 50 mb. in 700 miles. This was followed by two similar well developed cyclones, after which a cold air mass started to cover South America.

Figs. 9–13 of June 1947 show the development of a cyclone in the antarctic front off the northern end of Graham Land, and its progress in an east-north-east direction beyond South Georgia. The instrumental traces, for this period, at the South Orkneys show the great clarity of the fronts, and are typical of the simplicity of many weather phenomena of the southern oceans.

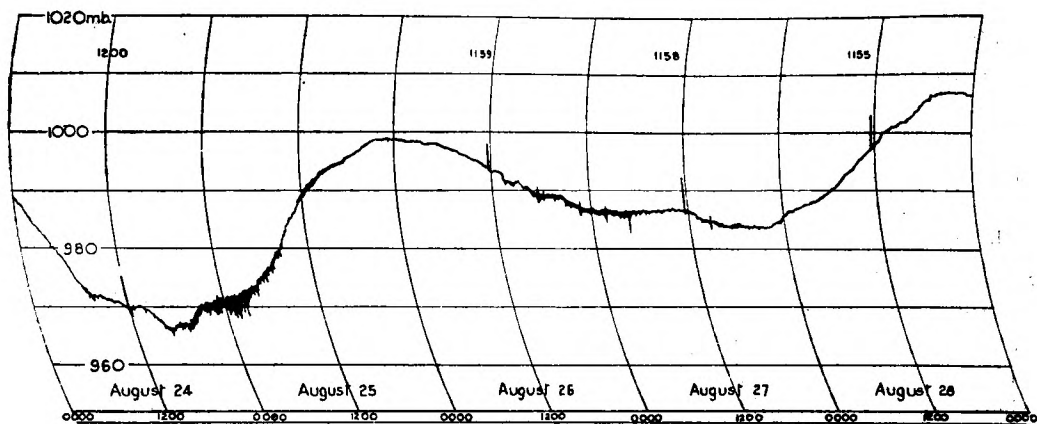


FIG. 2—TRACES FROM BAROGRAMS AT SIGNY ISLAND, AUGUST 1947
The broadening of the trace is due to a suction effect in high winds

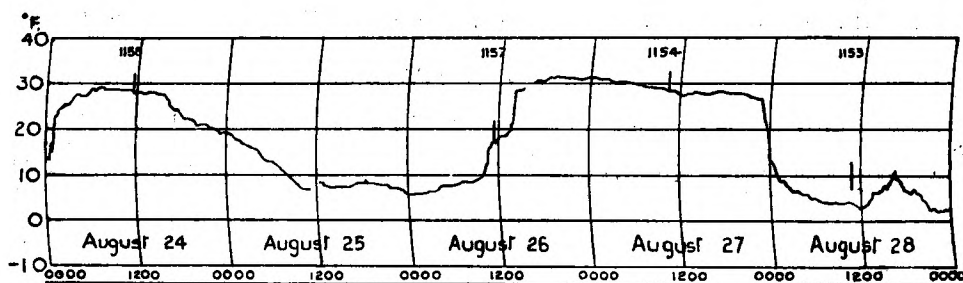


FIG. 3—TRACES FROM THERMOGRAMS AT SIGNY ISLAND, AUGUST 1947
The breaks in the trace are due to instrumental failures

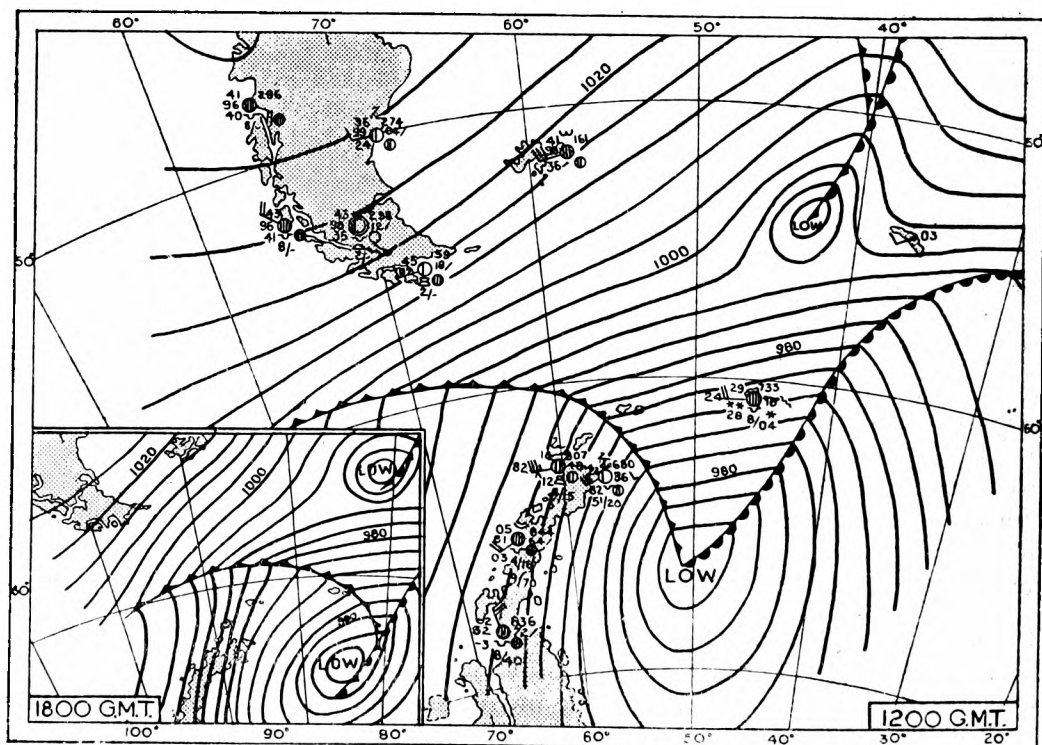


FIG. 4—SYNOPTIC CHARTS, SOUTH ATLANTIC, AUGUST 24, 1947



METEOROLOGICAL STATION AT SIGNY ISLAND, SOUTH ORKNEYS

The local harbour, Borge Bay, fills the centre of the picture and Coronation Island is in the background



OROGRAPHIC CLOUD COVERING CORONATION ISLAND

Photograph taken from the south during a northerly wind



Reproduced by courtesy of Mrs. G. A. Clarke

MR. G. A. CLARKE

Mr. G. A. Clarke, who was well known for his cloud photographs, died on February 13, 1949.
An obituary notice appeared in the May issue of this Magazine

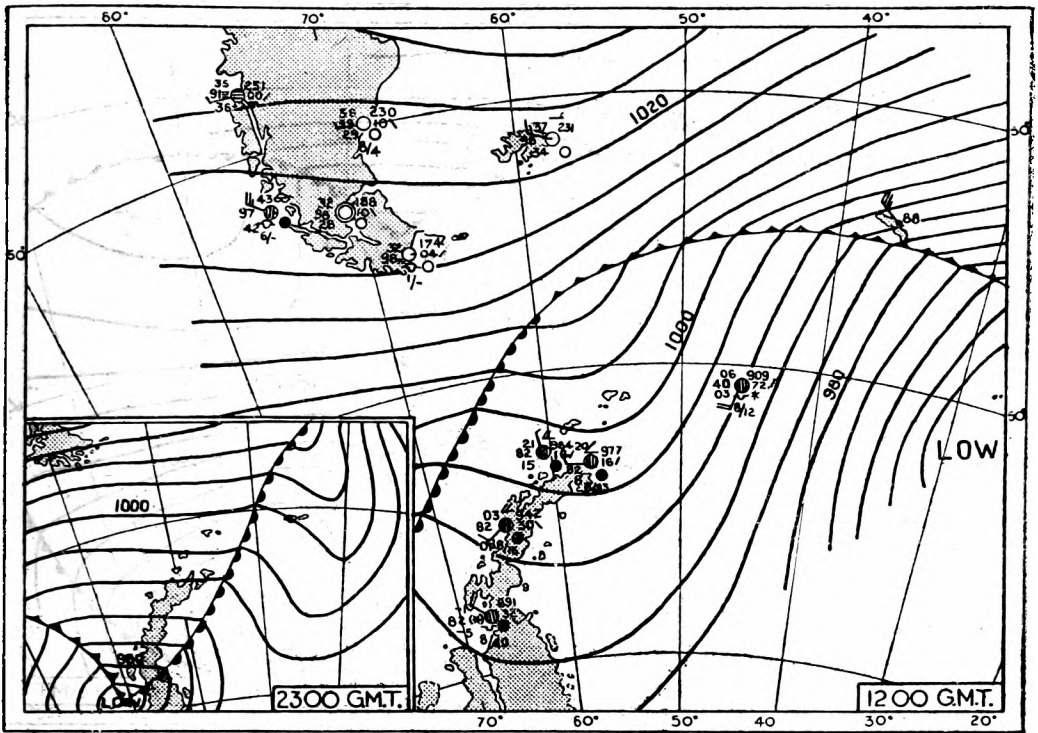


FIG. 5—SYNOPTIC CHARTS, SOUTH ATLANTIC, AUGUST 25, 1947

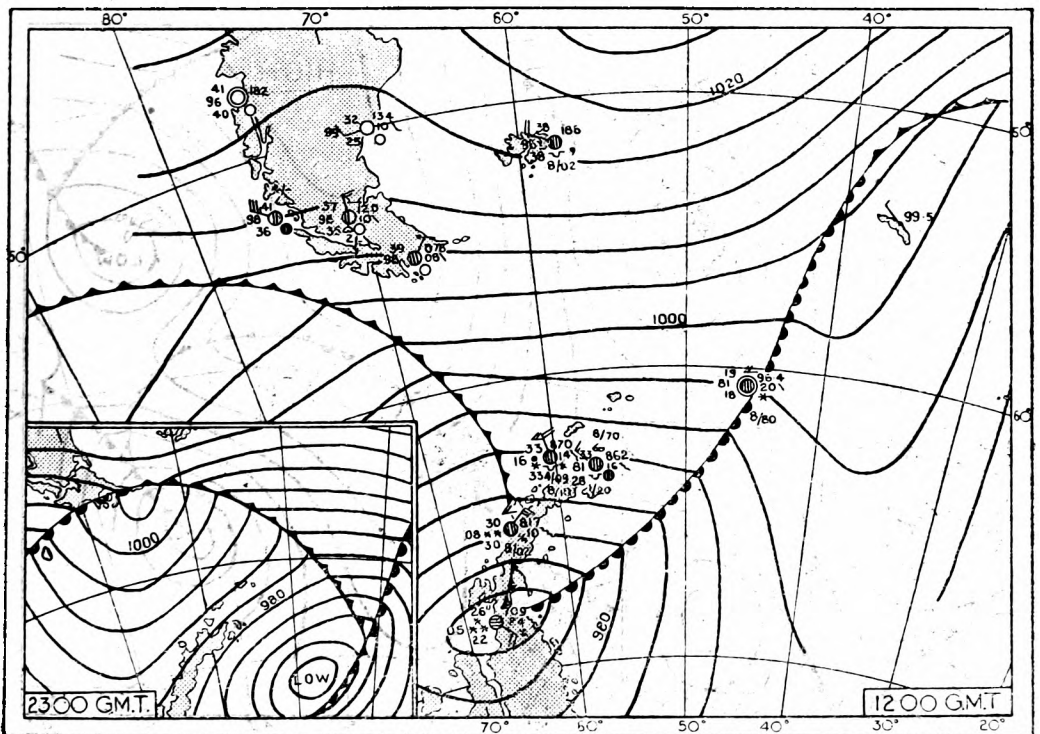


FIG. 6—SYNOPTIC CHARTS, SOUTH ATLANTIC, AUGUST 26, 1947

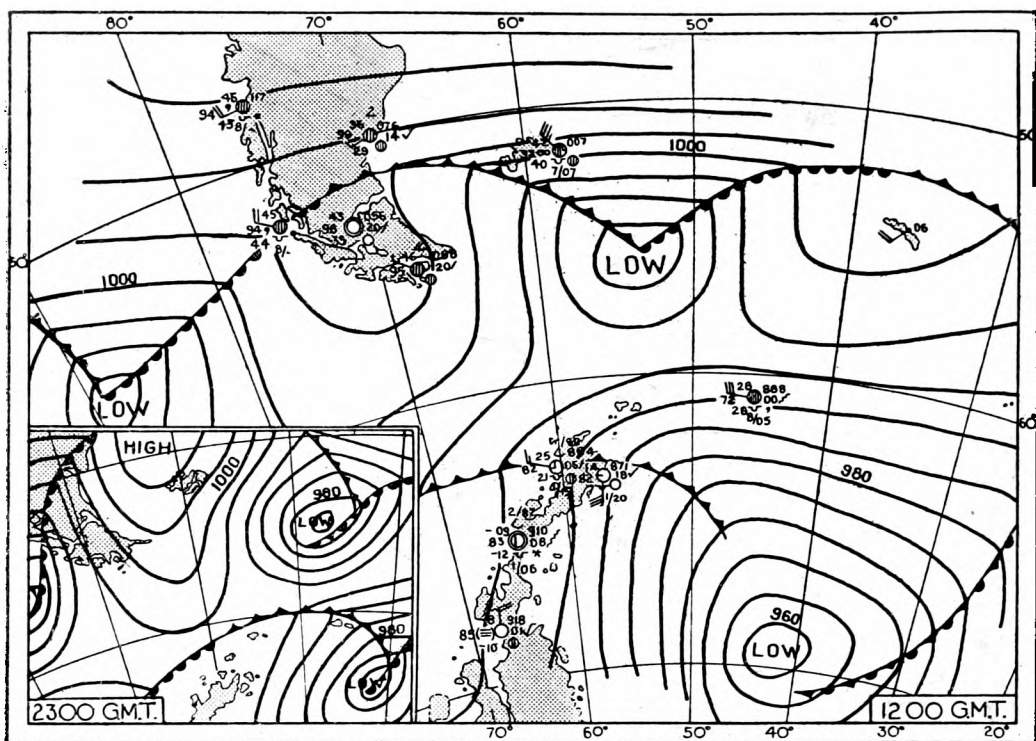


FIG. 7—SYNOPTIC CHARTS, SOUTH ATLANTIC, AUGUST 27, 1947

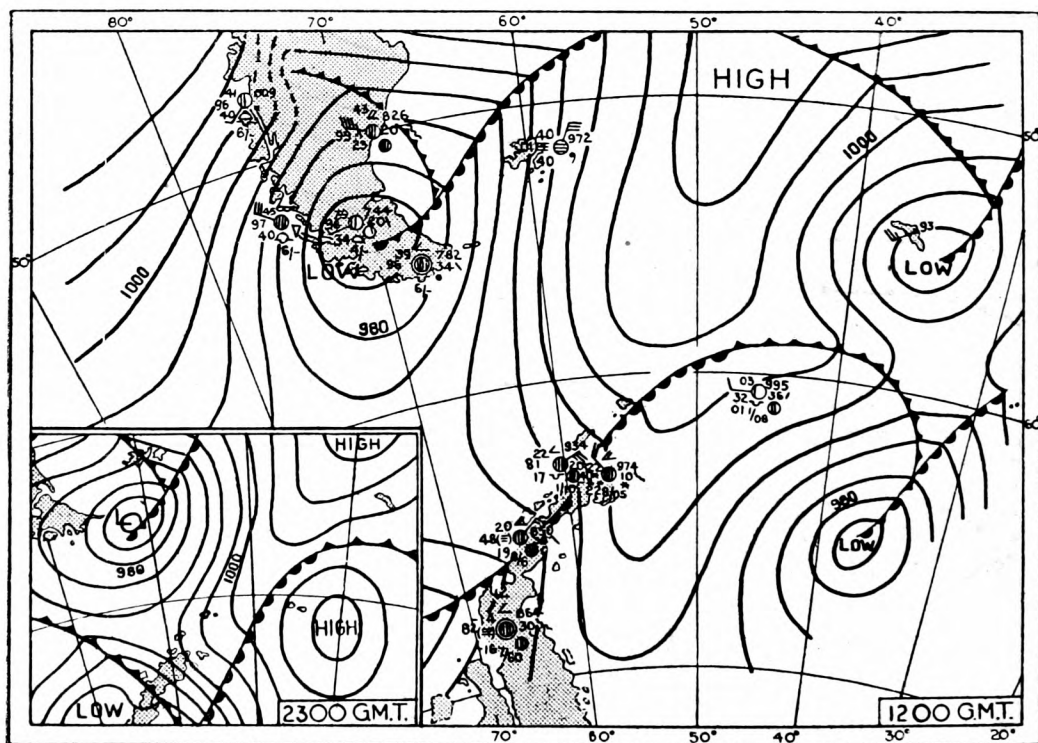


FIG. 8—SYNOPTIC CHARTS, SOUTH ATLANTIC, AUGUST 28, 1947

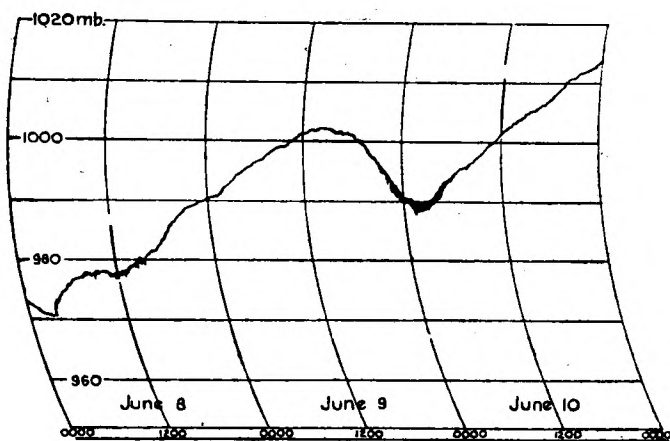


FIG. 9—TRACES FROM BAROGRAMS AT SIGNY ISLAND, JUNE 1947

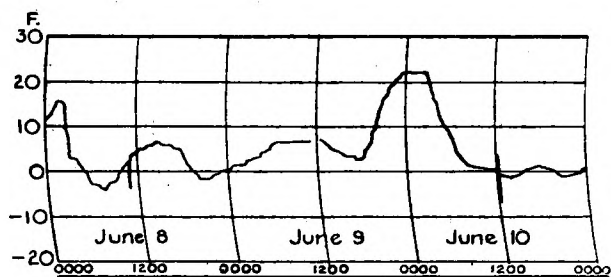


FIG. 10—TRACES FROM THERMOGRAMS AT SIGNY ISLAND, JUNE 1947

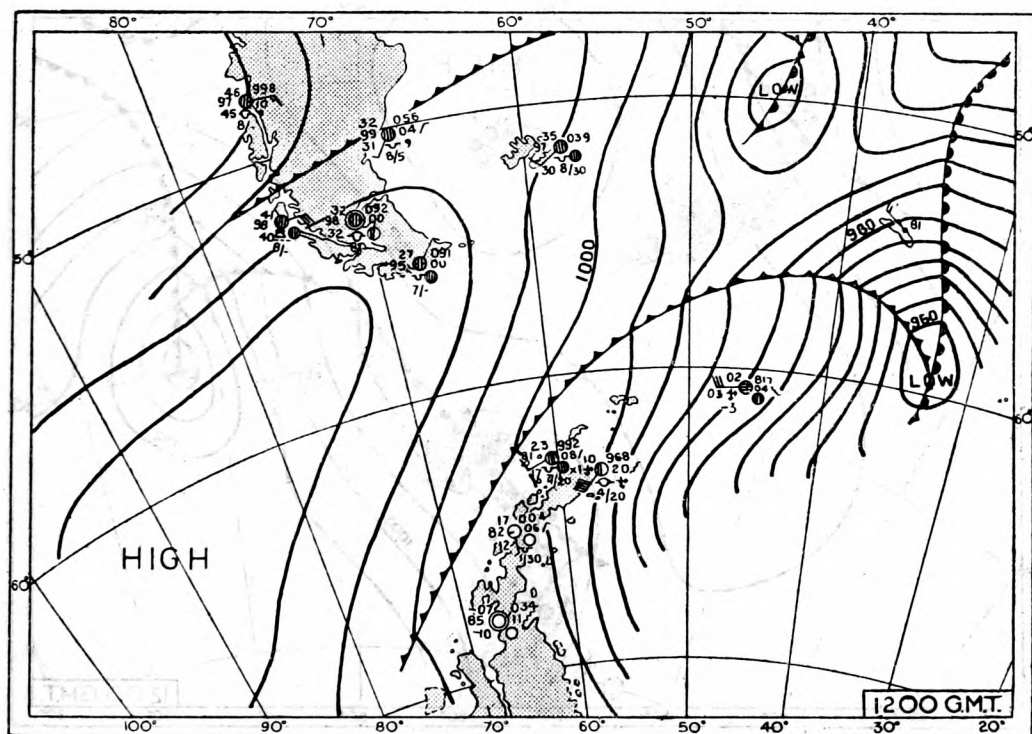


FIG. 11—SYNOPTIC CHART, SOUTH ATLANTIC, JUNE 8, 1947

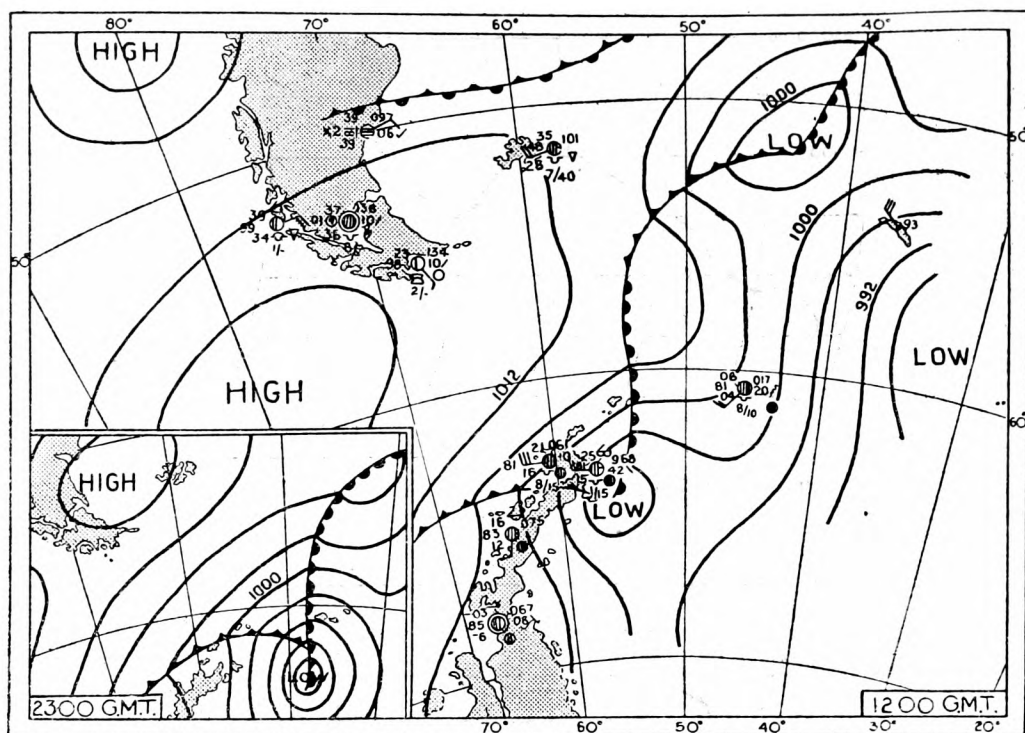


FIG. 12—SYNOPTIC CHARTS, SOUTH ATLANTIC, JUNE 9, 1947

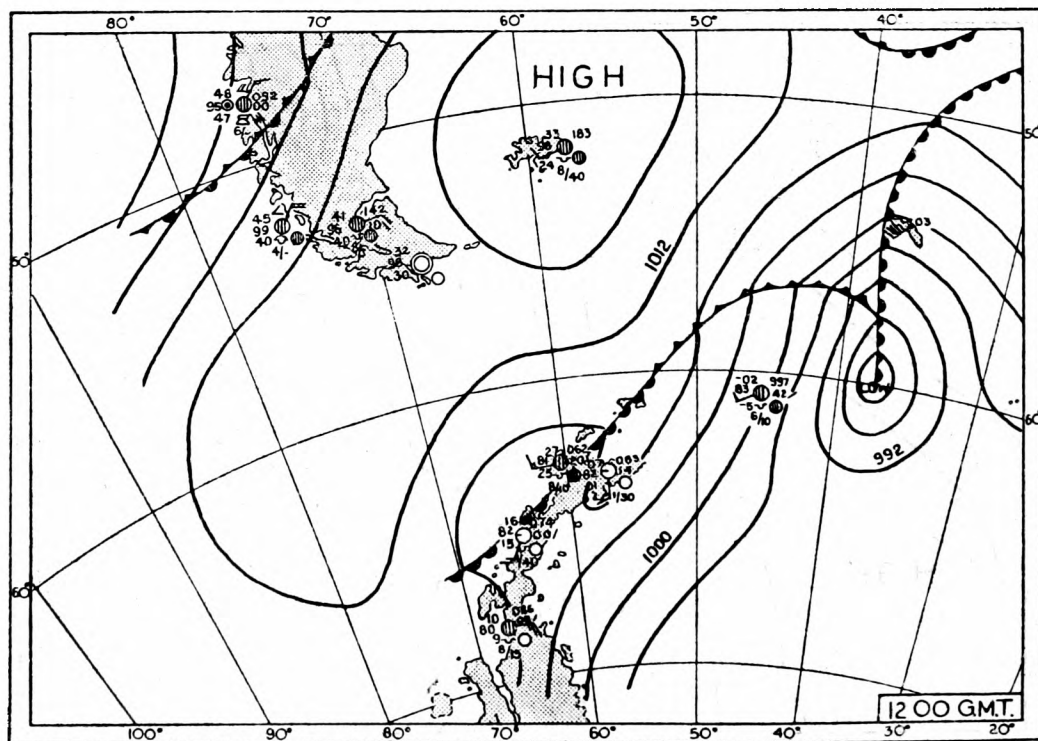


FIG. 13—SYNOPTIC CHART, SOUTH ATLANTIC, JUNE 10, 1947

Charts for November 24-25 show a third type of cyclone, experienced in 1947 in October and November, in which the cyclone forms on a meridional front passing Cape Horn. This carries air (Tm) much warmer than normal

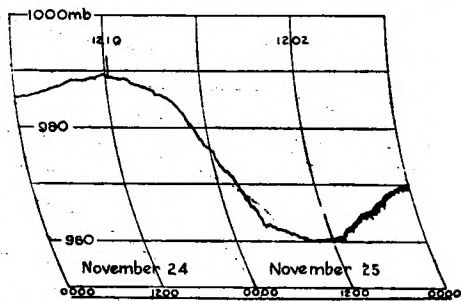


FIG. 14—TRACES FROM BAROGRAMS
AT SIGNY ISLAND, NOVEMBER 1947

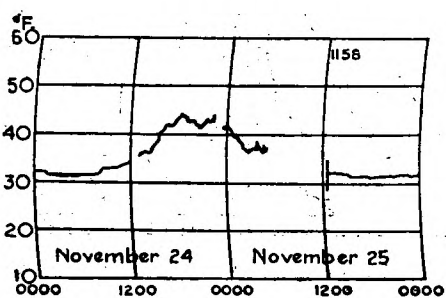


FIG. 15—TRACES FROM THERMOGRAMS
AT SIGNY ISLAND, NOVEMBER 1947
The breaks in the trace are due to
instrumental failures

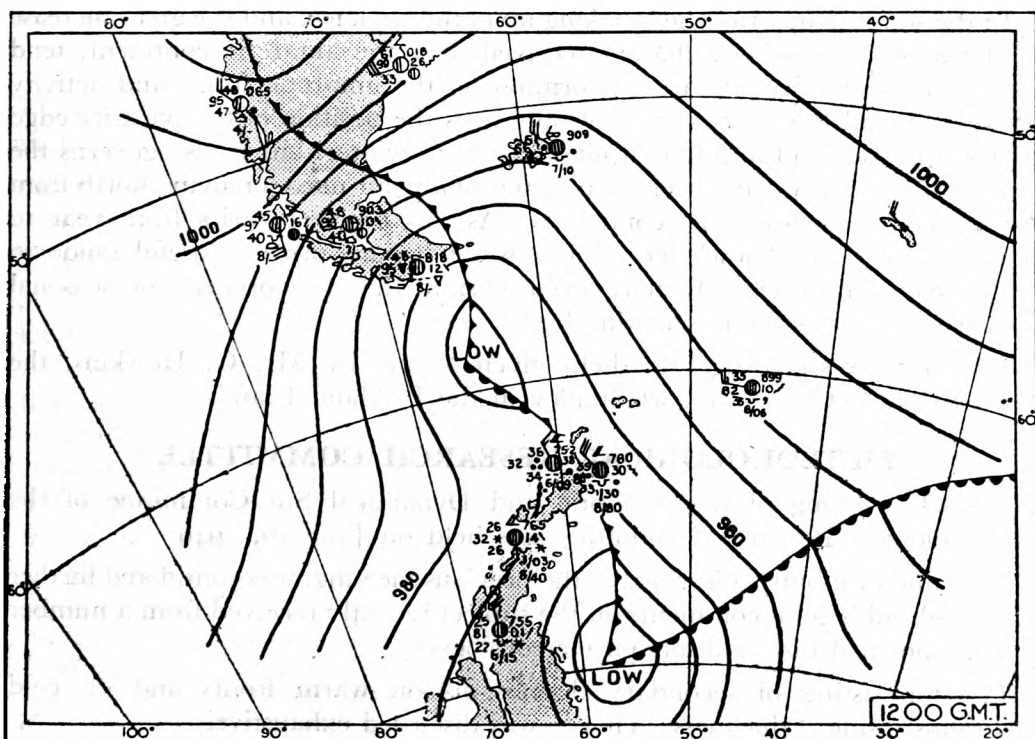


FIG. 16—SYNOPTIC CHART, SOUTH ATLANTIC, NOVEMBER 24, 1947

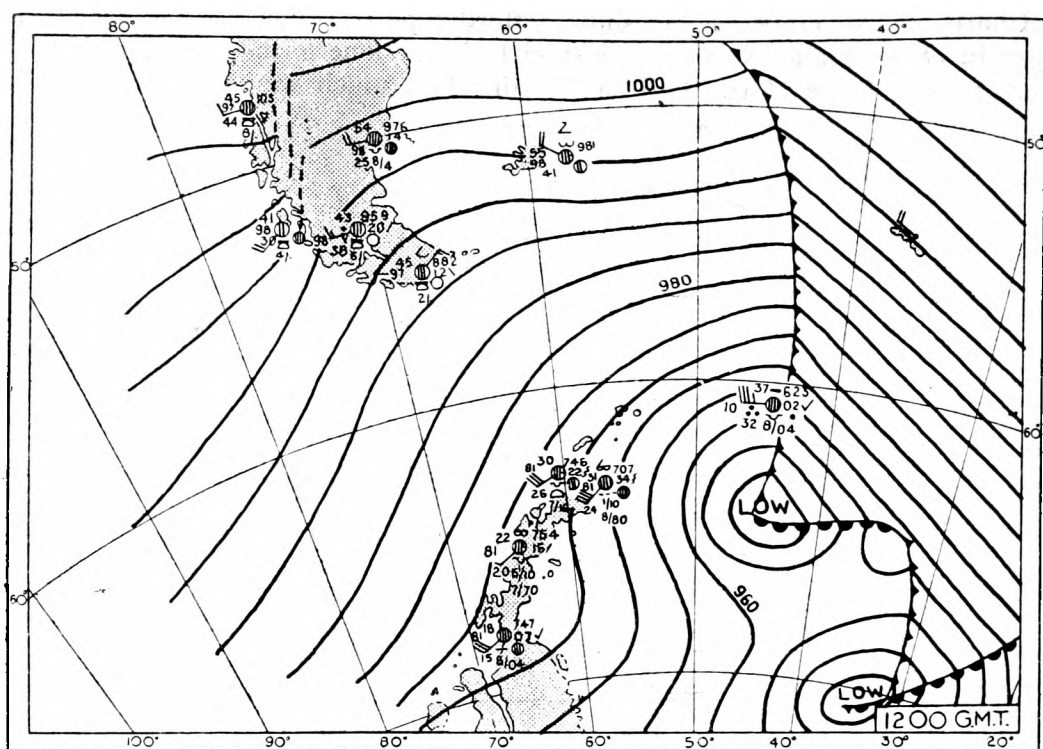


FIG. 17—SYNOPTIC CHART, SOUTH ATLANTIC, NOVEMBER 25, 1947

over the South Orkneys; and on Signy Island temperatures as high as 50°F . (although not on this occasion) were recorded due to orographic effect, plus breaking up of a surface inversion by the much higher Coronation Island to the north.

In the summer months, the breaking up of the pack ice, and the great increase in the amount of solar radiation received over the antarctic continent, tend to prevent sharp frontal surfaces forming on the antarctic front, and activity between A and Pm air ceases. Not only does the position of the pack-ice edge govern the course of antarctic-front cyclones in winter, but it also governs the time available for heating over open water, of any air masses moving north from Antarctica to the southern continents. As this position varies from year to year, a continuous knowledge of its position would prove a useful guide to antipodean forecasters. It may even permit the development of seasonal forecasts on a reasonable scientific basis.

I wish to acknowledge the help given to me by Mr. G. Howkins, the Meteorological Officer at Port Stanley in the Falkland Islands.

METEOROLOGICAL RESEARCH COMMITTEE

The sixth meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on June 16, 1949.

Dynamic instability, discussed at the previous meeting, was considered further in the light of helpful comments on the subject recently received from a number of well known British and foreign meteorologists.

The forecasting of secondary depressions on warm fronts and on cold occlusions, using "thickness" charts, was discussed exhaustively.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Weather on the west coast of tropical Africa from 20°N. to 20°S. including the Atlantic Ocean to 25°W.

This handbook has been prepared primarily for the use of Meteorological Officers on H.M. Ships, and it summarises the available statistical and descriptive material on the weather on the west African coast between 20°N. and 20°S., and over the Atlantic Ocean to 25°W. It is intended to provide these officers with a general description of the climates of the region and of local variations within the climates.

In the early part of the volume the general climatic features of the whole region are described and there are also more detailed climatic summaries for smaller areas. The remainder of the text deals with each of the meteorological elements in turn, giving mean and extreme values; local notes and notes on forecasting are included wherever possible. The text is illustrated by 71 maps and diagrams, and an appendix contains many statistical tables and a bibliography. (M.O.492, Price: 5s. od.)

Meteorology of airfields, by C. S. Durst, B.A.

“Meteorology of airfields” is written primarily to supply the designers of airfields with the type of data they need, and to show in what way meteorological data can be used for their purposes. The book deals in succession with visibility, cloud, flying-fitness figures, precipitation, wind, pressure and temperature; in each case the frequencies of occurrence are related to physical causes in an endeavour to show how the principles learnt in one region may be applied and modified to suit another. The examples chosen embrace many countries, principally those which were the scene of operations during the late war. As an appendix, tables are included of the frequencies of poor visibility and low cloud height at many of the principal airfields of the world.

(M.O.507, Price: 2s. od.)

The following publications will be published within the next six to nine months:—

GEOPHYSICAL MEMOIRS

No. 85—*Upper winds over the world*. By C. E. P. Brooks, C. S. Durst, N. Carruthers, D. Dewar and J. S. Sawyer.

The problem attacked is to construct roses of wind speed and direction for any place on the earth's surface at any height above sea level up to 40,000 ft. Actual observations are quite insufficient for this purpose, but it was found* that in the free air the distribution of the winds approximates to the normal circular distribution about the vector mean wind. Hence a wind rose can be constructed if the vector mean wind and standard vector deviation are known. The evidence for this is recapitulated in Part I and tables are given to facilitate the calculations.

Outside the tropics the vector mean wind can be calculated from the distance apart of lines of equal height of the isobaric surfaces, and Part II of the memoir

*BROOKS, C. E. P., DURST, C. S. AND CARRUTHERS, N.; *Upper winds over the world*. Part I. The frequency distribution of winds at a point in the free air. *Quart. J. R. met. Soc., London*, 72, 1946, p. 55.

gives world charts on Mercator's projection of the mean heights of the isobaric surfaces of 700, 500, 300, 200 and 130 mb. for the four seasons December to February, March to May, June to August and September to November, with an account of the method of construction.

Part III gives charts of the mean standard vector deviation for the same levels and seasons. These were made possible by the discovery that nearly up to the level of the tropopause the product of the standard vector deviation with the air density is in most cases constant for any one place and season. For much of the world the values had to be extrapolated from known regions, and the method of doing this is described.

Between latitudes 25° N. and S. the geostrophic relation between pressure gradient and wind does not hold, and for these regions seasonal charts of stream-lines and mean vector speed of the wind were constructed up to the level of 200 mb.; for 130 mb. the data were insufficient.

No. 86—*Solar radiation at Kew Observatory*. By J. M. Stagg, M.A., D.Sc.

The following paragraphs give a brief advance abstract of this forthcoming *Geophysical Memoir*.

The continuous records of direct solar radiation at normal incidence maintained at Kew since 1932 are discussed in the first half of the paper, and the measurements of total short-wave radiation on a horizontal surface from sun and sky together, and sun alone, made since 1946, are dealt with in the second part.

Both parts open with a description of the instruments and their standardization. Statistical treatment of the records follows with monthly and annual totals for all days and daily totals and extreme values for selected days of clear sky and high radiation. A particularly interesting feature is a tabulation of the three components of the incoming solar radiation for clear days computed from hourly values of the normal radiation and from the sun's altitude and azimuth. The variation of incoming radiation with time of day, solar altitude and mass of air traversed by the beam ("air mass" in the radiation sense) are tabulated and discussed. Transmission coefficients and turbidity factors are computed. A comparison is given between diffuse short-wave radiation from clear and cloudy skies and, finally, there is a discussion of the average relation between total and diffuse sky radiation for the four seasons. A detailed discussion of the physics of all topics dealt with is provided.

ROYAL METEOROLOGICAL SOCIETY

General circulation of the atmosphere

At the meeting of the Society on May 18, with Mr. E. Gold, F.R.S., Vice-President, in the Chair, a discussion was held on the general circulation of the atmosphere.

The discussion was opened by Dr. E. T. Eady, who described his recent researches on the dynamics of atmospheric waves and the transfer of heat from equator to pole and from the lower to the upper atmosphere. He pointed out that the earth's surface polewards of latitude 35° and the upper atmosphere everywhere lost heat by radiation on the whole, and the earth's surface equatorwards of 35° gained heat by radiation, so that a mechanism was needed

to allow of the transport of heat to the regions losing it by radiation from those which gain it, and also to provide the transference of momentum, without which the earth's atmosphere would soon be brought to relative rest by skin friction. The necessary transfer of heat and momentum was carried out by atmospheric eddies which arise as a result of the dynamic instability of any steady baroclinic motion. Dr. Eady said that, in a paper to be published shortly in the new Swedish journal *Tellus*, he had shown, from the equations of motion and realistic boundary conditions, the existence of two dominant types of atmospheric eddies. One of these had a long wave-length such that there might be six associated troughs around the northern hemisphere and the other had a short wave-length and corresponded to the so-called wave depressions. The transport of heat by the eddies was included in his paper but he had not been able to calculate the momentum transport for any realistic system. There was an essential difficulty in the calculation of the flow of momentum in that the momentum of an air particle or of any associated quantity such as angular momentum, vorticity, etc., was not conserved to even a limited extent as the particle moved.

Dr. Forsdyke then described the work of Priestley on heat transport and zonal stress between latitudes, published in the Society's *Quarterly Journal**. Priestley calculated the meridional flux of heat, water vapour, and momentum for two years at Larkhill. An adequate treatment of the problem would involve computations based on a number of stations well distributed round a given parallel of latitude; the present work, limited as it was to one station, was intended only to indicate the possibilities and method of such computations. The flux of heat was evaluated for both sensible (proportional to $c_p T$) and latent heat. The flux was separated into a steady advective flux and an eddy flux. As regards heat it was verified that the atmospheric eddy flux is of the magnitude required to equalise the heat gains and losses by radiation, while for momentum it was confirmed that the zonal stress arising from deep meridional currents can maintain wide zonal circulations against friction. The eddy flux of sensible heat is northwards in the lowest layers at all seasons, but is reversed at all seasons at a variable level in the middle or upper troposphere. There is no corresponding reversal in sign of the mean horizontal temperature gradient at this level. The flux of latent heat is northwards at all significant levels and is negligible above 400 mb.

Dr. R. C. Sutcliffe gave a contribution on the synoptic aspect of the general circulation. It had been shown, by Brunt and others, that under reasonable assumptions the kinetic energy of the atmosphere would be dissipated by friction in 5 or 6 days. This suggested to him that the atmosphere balanced its books every week or so, and that the relatively short-period types or "modes" of the circulation pattern which often lasted for weeks had as much right to be called the general circulation as had an average over many years, which was never, in fact, realised at any one time. Dr. Sutcliffe showed slides illustrating a number of these patterns, including (a) the meridional pattern with a preponderance of wind along the meridians in both directions, (b) the double-structure pattern with a ring of depressions in the far north, a ring of anticyclones in middle latitudes and then a further ring of depressions towards the subtropics, (c) the summer monsoon type of low pressure over the continents,

*PRIESTLEY, C. H. B.: Heat transport and zonal stress between latitudes. *Quart. J. R. met. Soc.*, London, 75, 1949, p. 23.

and finally (d) the inverted winter monsoon type with high pressures in the north of the hemisphere and low pressures in the south which was so persistent in February 1947.

In the general discussion which followed, Professor Sheppard said the stratosphere seemed to have been neglected and pointed out that though the density was small, yet the measured winds were so high that they gave a large mass transport, Mr. Brewer referred to the difficulties of explaining the chemical constitution of stratospheric air which had such a low relative humidity over England that it seemed the air must have come northwards from the subtropical stratosphere, and Mr. Sawyer suggested that it would be more useful to study one of the other thermodynamic parameters rather than the heat transport as computed by Mr. Priestley; the transport of internal energy or total heat might prove more satisfactory.

ROYAL INSTITUTE OF BRITISH ARCHITECTS

Professor Gordon Manley gave an Architectural Science Board lecture at the Royal Institute of British Architects on April 12, 1949. The lecture was entitled "Microclimatology: Local variations of climate likely to affect the design and siting of buildings".

Professor Manley opened his lecture by suggesting that microclimatology is largely the geographer's problem as it is concerned mainly with assembling and interpreting existing data. In applying results from microclimatology, architects may have to use the technique of botanists; they must certainly ensure that any exotic forms of architecture should be suitable not only for the weather usually experienced, but also for the extremes which occasionally occur.

The incidence of frost varies widely over comparatively small distances, because of topographical effects. These effects exert most influence on radiation nights, which occur as frequently as two nights out of five. In Worcestershire, for example, it is more frosty at Perdiswell (in fairly level farmland) than on the sloping land of Malvern; at Droitwich, where the climatological station is well down on the Severn plain, it is frostier still. Professor Manley pointed out the importance of applying frost data only to areas near the screen and not, necessarily, to a whole town. The effect of soil on frost can be illustrated from Lynford, where the soil is sandy, and Cambridge, on a clay loam. On the coldest nights in each month, Lynford is on the average about 6°F. colder than Cambridge. Generalising, it can be said that the frost-free season is only about two months on extensive sandy lowlands, and as long as seven months in urban sites. The extreme summer temperatures with which British architects must reckon are about 90°F. in the north and 100°F. in the south; the extreme winter temperatures are around 0°F. in the south-west, -10°F. in the Midlands and -20°F. in Scotland. Penetration of frost is clearly important, and in 1895 this was 3 ft. or more. Some frost penetration must be expected even in the West Country, because of the lack of snow cover.

Architects will naturally be concerned to avoid very foggy areas and Professor Manley quoted a number of examples of the drift of industrial smoke, in the Midland Valley of Scotland, along the Great North Road between Doncaster and Wetherby, and in Snowdonia, where the smoke drifts from Lancashire when there is a NE. wind up to some 2,500 ft. At Leicester, smoke on the lee side cuts down the ultra-violet radiation received.

Shelter from strong winds is necessary to prevent undue heat loss, but careful judgment is necessary to avoid frost areas, which are usually in sheltered spots. Land and sea breezes are usually not very important to architects, unless they carry smoke with them. The helm wind is an example of a local wind which has had some influence on local architecture; the strong NE. wind blows down Cross Fell, and few doors are built on this side of farm houses; some shelter is also obtained from trees to the north-east of the houses.

For snow fall and snow lying, the average frequency can be obtained from published maps. Professor Manley suggested that, for inhabited levels, if n is the average frequency of snow lying, the maximum number of days with snow lying likely to be experienced in any year is about $n + 50$. There are few places in this country where the record depth of snow is less than 2 ft., and heavy falls and drifting over roads can paralyse traffic at times. Drifting could be lessened by avoiding wind-swept areas when building roads, and by the careful planting of belts of trees a little distance from the roads.

Finally, Professor Manley dealt with the modification of local climates by buildings; the reduction of wind speed and the increase in minimum temperature are important to architects. On still, clear nights the centre of Manchester is some 10°F. warmer than the surrounding countryside in the summer, and 6–7°F. warmer in winter.

The discussion was then opened by Dr. Glasspoole, who said that architects should have some idea of what the meteorologist aims at recording for each element, and of the work involved in summarising the data. For example, 200,000 computations are necessary to obtain the mean wind speed and direction over 10 years from a Dines' anemometer. Rainfall is the element for which we have the most complete picture, and average rainfall maps were being published by the Ordnance Survey on a scale of 10 miles to the inch. Intense rainfall is important to architects; this is very local, and many more records would be needed before we could improve on our present knowledge of its distribution.

Miss Frisby stated that she had worked with architects and had come to the conclusion that the climatologist was expected to be a jack of all trades. In general, the climatic information which was required by the architect was not available and had to be inferred from what was available. Even then, architects preferred that it should be presented not in meteorological terms but in recommendations as to the type of heating or construction which should be used.

Dr. Brooks expressed the view that smoke was one of the most potent climatological elements in this country, and said that London smoke could be traced as far as Norwich.

Mr. Hibberd was critical of the organization of the consultation between architects and meteorologists, and said that meteorologists had not been consulted until eighteen months after the sites had been chosen for some new towns. He thought that sound was important in deciding where to live and that it should be studied by microclimatologists.

Mr. Robinson pointed out some ways in which climate affects domestic architecture. In Lancashire, dormer windows are less popular than in the south because they tend to let in rain; also 9-in. walls are much more common in London than in the north.

Mr. Hogg said that the lecture had dealt with problems which were also important in agricultural meteorology. He gave an example to show the effect of sloping ground on the incidence of the sun's rays and said that the Meteorological Office intended to co-operate with agricultural colleges in studying the microclimates on various slopes and aspects. He pointed out that it was important for architects to appreciate that the warmest slopes often face somewhat west of south, and not due south.

Mr. Oddie dealt with the problems of the lay-out of towns and estates, and was critical of some modern estates. He said that Le Play believed that the lay-out of mediæval towns was the result of an instinctive knowledge of the local variations of climate. In those times, the builders knew intimately the neighbourhood in which they were working, but today this is by no means always so.

The Chairman agreed with this last point and the meeting accorded its thanks to Professor Manley.

LETTER TO THE EDITOR

Formation of rain

In connexion with the problem of rain from non-freezing clouds it is of some interest to point out the similarity of conditions in which this phenomenon has been reported. Some past published observations have been given in the papers quoted below and a number of new ones will be described by E. J. Smith in a forthcoming publication. All the reports agree in showing rain as occurring

- (a) in maritime or coastal districts,
- (b) in tropical or subtropical regions,
- (c) where the cloud type is reported it is stratified or only moderately turbulent.

In moderate climates, warm-sector drizzle is observed in tropical maritime air, *i.e.* under somewhat similar conditions. No rain proper from non-freezing clouds appears to have been reported and documented from any place more than fifty miles inland although thick clouds which do not reach freezing level are frequent in the summer of Europe, Australia and, presumably, America.

It is possible that in maritime situations, sea spray provides a few and relatively large condensation nuclei which are able to attract all the available water vapour. In this connexion it is of interest that the minimum number of condensation nuclei was observed over the ocean. Inland, the salt nuclei may divide and other nuclei become more numerous.

A theoretical discussion which is to be published in a forthcoming issue of the *Australian Journal of Scientific Research* shows further that a great heat content and very slow cooling are conducive to the formation of few and relatively large drops which in turn may have some bearing on the points (b) and (c) above.

E. B. KRAUS

C.S.I.R. Radiophysics Division, Sidney, N.S.W., June 9, 1949

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NOTES AND NEWS

Anomalous radar propagation over land in the period November 29 to December 1, 1948

Towards the end of the extensive foggy period which persisted over most of England in the latter part of November 1948, unusually long ranges on permanent echoes were obtained at the 10-cm. radar station at East Hill, near Dunstable. The equipment was only available at intervals in the period from November 29 to December 1, but echoes were received frequently from high ground at ranges up to 145 miles (the maximum range which could be measured with the equipment). The normal range from which ground echoes are received is only 10–15 miles so that it is of interest to examine the meteorological conditions which gave rise to this anomalous propagation.

It is well known that the meteorological factors necessary to give sufficient bending of the radio rays to cause unusually long ranges to be observed are the existence of a temperature inversion of sufficient magnitude or a sufficiently great humidity lapse or a combination of both. The critical condition for temperature effect alone is an inversion of about 1°F. in 17 ft. and for the water-vapour effect alone a lapse of water-vapour pressure of 1 mb. in 100 ft.*

During the morning of the 29th permanent echoes were seen on many bearings at ranges up to 145 miles. The "Balthum" kite-balloon temperature and humidity ascent at Cardington for 0730 G.M.T. on that morning showed an inversion of temperature, commencing at 500 ft., which (according to the readings of the Downham Market radio-sonde) extended to 2260 ft. The total temperature inversion was 23.6°F. of which 15.2°F. occurred in the first 200 ft., *i.e.* from 500 to 700 ft. The temperature inversion therefore was sufficient between 500 and 700 ft. to give super-refraction but in the same interval of height the vapour pressure increased from 5.2 mb. to 7.2 mb. and therefore acted against the temperature inversion, and it can be shown that the increase of vapour pressure completely nullified the effect of the temperature inversion. By 1200 G.M.T., however, although the magnitude of the inversion in the 500–700-ft. layer had decreased to 10.2°F. the vapour pressure had also changed considerably and now decreased from a value of 5.3 mb. at 500 ft. to 2.5 mb. at 700 ft. giving a lapse of vapour pressure in excess of that necessary for super-refraction. On November 29, therefore, it seems likely that the abnormal radar ranges obtained were due to the development between 0730 and 1200 G.M.T. of a super-refracting layer between 500 and 700 ft. Any obstruction, such as high ground, which protruded into this layer would be expected to give a much greater than normal radar echo. The existence of such echoes to ranges of 145 miles at least indicates that the super-refracting layer was continuous over a wide area. It is of interest to note, however, that all the radio-sonde ascents for that day at Larkhill and Downham Market failed to indicate low vapour pressures at

*APPLETON, SIR EDWARD; The influence of tropospheric conditions in ultra-short-wave propagation. Meteorological factors in radio-wave propagation. London, 1947.

800 ft., the dry air being in all cases above this level. This suggests that the dry air extended down to the 700-ft. level only for a period between 0900 and 1500 G.M.T. (the times of the radio-sonde ascents).

On the 30th, abnormal ranges were again observed, but according to the "Balthum" ascents for that day, there was no layer below 1,000 ft. in which super-refraction was possible. The Downham Market 0900 radio-sonde ascent, as published in the *Daily Weather Report*, does not indicate any possibility of a super-refracting layer but somewhat greater detail obtained from the working sheet showed that the vapour pressure fell to 1.3 mb. at 2,050 ft. while the Cardington ascent for 0730 showed the vapour pressure to be 7.4 mb. at least as high as 1,000 ft. In the layer from 1,000 to 2,000 ft., therefore, there was a vapour pressure decrease of 6.1 mb. and, in view of the abnormal ranges observed, the probability is that this decrease took place in a layer of 600 ft. or less.

On December 1 ranges up to 134 miles were obtained between 1100 and 1300 G.M.T. on bearings between north-west and south-east through north, but none on any other bearings. After 1300 all the abnormal echoes disappeared and this coincided with, or was soon followed by, the final dissipation of the fog. Once again the "Balthum" ascents showed no possibility of a super-refracting layer below 1,000 ft. but, in conjunction with the Downham Market ascent for 0900, indicated the probability of a vapour-pressure lapse of about 4.6 mb. between 1,000 and 1,800 ft. There was probably a super-refracting layer within the 1,000-1,800-ft. layer which was destroyed after about 1300 G.M.T. due to the spreading out of the vapour pressure lapse through too great an interval of height by turbulent mixing. (The wind at 2,000 ft. was 23 kt. compared with less than 10 kt. on the previous days examined.)

It is clear that the abnormal ranges observed during this period were associated with a rapid lapse of humidity above the fog but the radio-sonde ascents as published do not give a sufficiently precise definition of the boundaries of the dry layers. The rate of ascent of the balloon (about 1,200 ft./min.) and time lag in the humidity element are probably mostly responsible but it is clear that (to the radio man) significant humidity changes are not specially reported in the same way as the temperature inversions.

R. F. JONES

Meteorology in 1815

In the first two decades of the nineteenth century important strides were made in the science of meteorology. Dalton's work on partial pressures, Luke Howard's classification of cloud types and theory of cloud formation by condensation of water vapour in rising currents of air, and the first rough observations of upper winds with pilot balloons belong to this period.

One of the leading meteorologists of the day, T. Forster, F.L.S., wrote a text-book surveying the meteorological knowledge of his time called "Researches about atmospheric phenomena" of which the first edition was published in 1812, the second in 1815 and the third in 1823.

These notes on meteorology in 1815 are prompted by the purchase for a small sum of a very sound copy of the second edition which has now been placed in the Meteorological Office Library.

Forster devotes much of his work to cloud structure. The reason for the "comparative levity" of clouds is examined at length. A current theory was that cloud particles were hollow and contained some gas lighter than air. Forster argues against this view and is in favour of the correct explanation of a very slow rate of fall "because of their minuteness". On the structure of cirrus cloud he was rather fantastic himself, regarding the long filaments as drawn out in some way electrically and serving as conductors of electricity to neutralise the electricity of remote masses of air. Although he knew well that wind varies with height he did not use that knowledge when considering cloud forms.

In those days, cumulonimbus with anvil was called cumulo-stratus, and regarded as produced by a cumulus cloud moving upwards and "inosculating" with cirrostratus. On the whole, however, Howard's classification of clouds, which is illustrated in this book by seven coloured figures, has stood the test of time extremely well.

Forster describes the first pilot-balloon observation in some detail. It was made by Mr. Wallis, who released "an inflammable air balloon of varnished paper 3 ft. 6 in. in diameter" from Clapton, London, on October 25, 1809. The balloon went first to west-north-west, then to south, and later north-east, as it rose. It fell at Wilbraham in Cambridgeshire. Forster himself later made over thirty similar flights, most of which he considered to indicate four or more different currents of wind. Naturally without observations of the elevation, etc., of the balloon this work was very rough.

The opinion at the time was strongly in favour of lunar influences on the weather. Forster, indeed, states "that changes of weather oftener take place about the full and new moon and about the quadratures than at other times is a fact founded on long observations." It does not seem to have been realised that with these lunar phases only seven days apart it was quite easy to ascribe changes as occurring "about" one or other of them.

For short-period forecasting the Shepherd of Banbury rules were in favour, but a great deal of space is given by Forster to prognostics based on the behaviour of animals, human aches, etc. The connexion between pressure variations, weather, and temperature were naturally hard to understand in 1815. Forster, recognising the relative lightness of warmer air, was very puzzled by occasions of rising pressure with increasing temperature.

A curious theory of "igneous" meteors to the effect that they were incandescent gases of the will-o'-the-wisp type ascending from the earth was current in 1815. Forster points out that no one had ever seen a column of burning gas rising from the earth to great heights and tentatively suggests that "igneous" meteors might be the same as aerolites, though why aerolites should burn in the upper air or where they came from, he could not see. The aurora is correctly ascribed, following Davy, to electric discharges in rarefied air.

Apart from meteorology the book contains a discussion on two matters of which much is heard today. On the first of these, whether science is pursued for the discovery of new facts or for its utility and extension of human power, Forster is wholly for discovery. The second matter, following a reflection on the decay of the ancient civilizations, is the need for the "permanent improvement of the moral and intellectual character of future generations, without which all the scientific records imaginable would be to them only as cyphers scrawled on the barrenness of intellect."

G. A. BULL

Visibility from Fairlight Down, near Hastings, Sussex, evening May 31, 1949

Fresh polar air covered the British Isles on May 30-31 and visibility was exceptionally good over much of the country.

An article by Mr. V. J. Torr in the *Hastings & St. Leonards Observer* of June 11 describing the view from Fairlight Down, 550 ft. above M.S.L. a few miles east of Hastings, Sussex, on the early evening of May 31, is of interest as illustrating the exceptional visibility.

To the north, the Darent gap, 35 miles away in the North Downs, and, to the east, Shakespear Cliff, 30 miles away, were visible. Across the Channel the higher parts of the French coast were visible from Cape Gris Nez (180 ft.) at 50 miles to the line of cliffs (about 250 ft. high) south of the Somme estuary at 70 miles distance.

Looming must be invoked to explain this visibility of the French coast, for the sea horizon from Fairlight Down is approximately 32 miles distant with normal refraction so that an eminence of at least the same height would be needed for visibility at even 64 miles. Cape Gris Nez would be barely visible from Fairlight with normal refraction as the horizon distance from it is about 19 miles. The wind was from between S. and SW. over the eastern Channel and the looming is probably to be accounted for by an inversion in air warmed over France moving out over the relatively cold sea.

It is interesting to recall the classic observation of looming made by W. Latham, F.R.S., from Hastings on July 26, 1798. On that occasion a considerable length of the French coast was seen from beach level. His account is reproduced in the "Manual of Meteorology" Vol. III, p. 58.

Record rainfall at Suva, Fiji

According to reports received from the Meteorological Office in the Fiji Islands, May 1949 was the wettest month on record at Suva with a total fall of 58.70 in., beating the previous highest of 45.45 in. in April 1941.

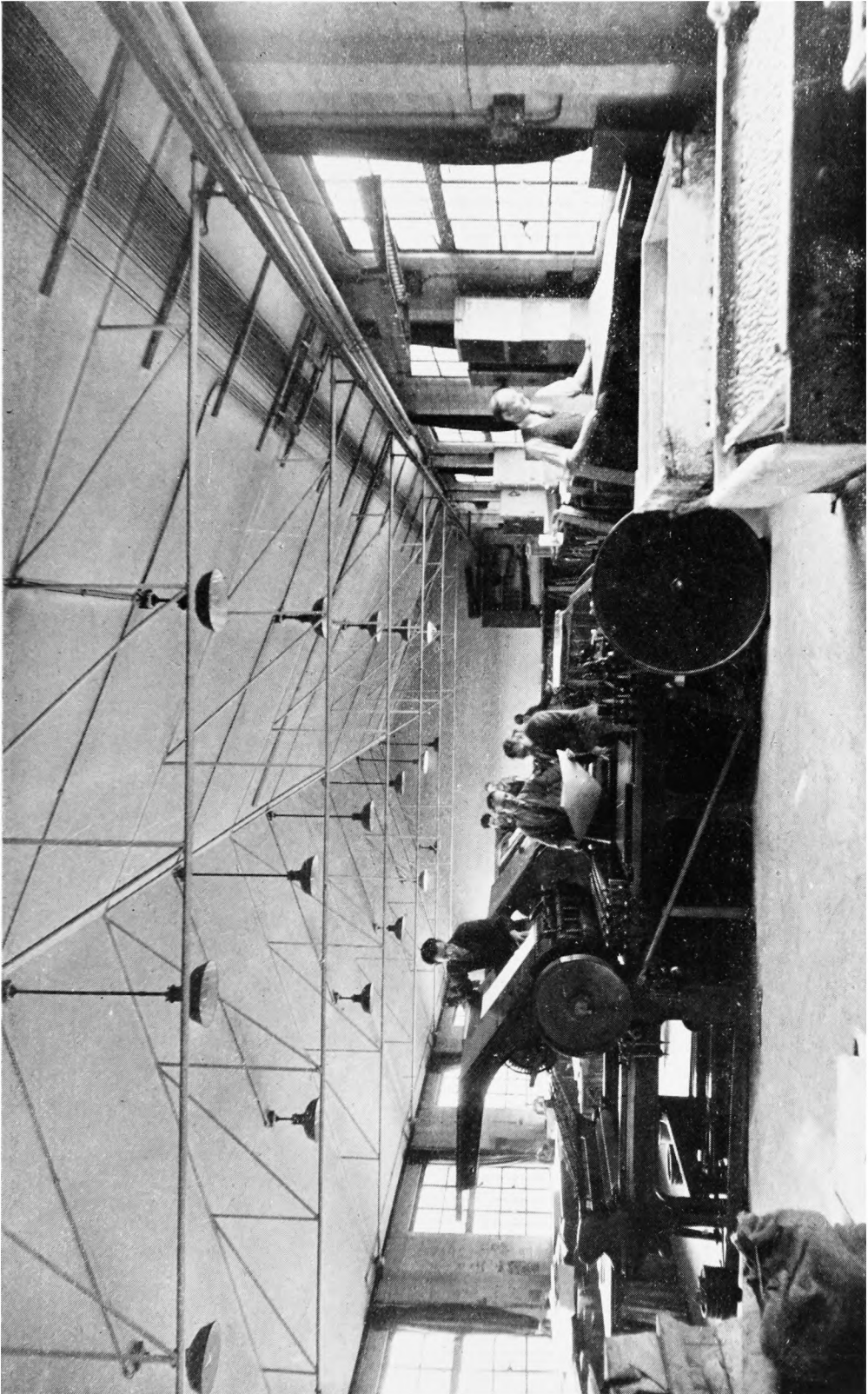
During the month, very heavy falls were recorded on the 5th of 14.53 in., on the 10th of 6.05 in., and during the night 28th-29th when 11.53 in. rain fell in a violent thunderstorm which lasted about 12 hr. An automatic gauge at Walu Bay measured a fall of 2 in. in 20 min. on the 5th. The fall of 14.53 in. on the 5th was the highest since the record daily fall of 15.91 in. which occurred on November 12, 1911.

Journal of Geophysical Research

(In continuation of *Terrestrial Magnetism and Atmospheric Electricity*)

The change of name recorded at the head of this note has been made in the title of one of the oldest of geophysical journals, with effect from No. 1 of Volume 54, March 1949.

The new editor, Dr. Merle A. Tuve, who succeeds Dr. J. A. Fleming, states in his greetings that the change of title does not represent a change in the journal itself, which is still under the control of the Carnegie Institute. The journal has for the past twenty years covered a wider field than the title indicated, having contained papers on the upper atmosphere, the ionosphere, the aurora, solar and terrestrial relationships, and investigations on the crust and interior of the earth which were not more appropriate to other specialist journals.



H.M. STATIONERY OFFICE PRESS AT DUNSTABLE, USED FOR PRINTING THE *Daily Weather Report*



FOLDING AND DISPATCHING THE *Daily Weather Report* AT DUNSTABLE

The change of name is intended to emphasise that the journal will be developed as an avenue for publication of the scientific aspects of geophysics, as distinguished from research and development work in geophysics directed to more immediately practical ends.

Notice to users of the Climatological Table for the British Commonwealth

The publication in the *Meteorological Magazine* of the Climatological Table for the British Commonwealth beyond the present year is being considered.

Users of the Table are invited to write to the Editor to say what use they make of the various data, and to make any suggestions as to how the Table can be made more practicable.

REVIEWS

Climate through the Ages, by C. E. P. Brooks. 8vo. $8\frac{1}{2}$ in. $\times$ $5\frac{1}{4}$ in., pp. 395. Ernest Benn, London. 2nd edn. 1949. Price: 21s. 6d.

English students of climatology are very ready to complain that there are too many observations and too little literature. There are those who have reached the stage of disillusionment which is liable to follow that romantic period in one's early twenties when, freshly equipped from the Sixth Form, the synoptic chart is still a glamorous object of contemplation. But as time goes on, lacking immediate association with an active-minded forecasting office, some take up particular studies: the aurora, the forms of clouds, the elegant glories of turbulent motion. Others, contemplating the world as a whole, find their thoughts turn to the range of possibilities in space and time that the world's weather has to offer, especially if their profession or business leads them daily to consider the effect of weather on the world's diverse activities from agriculture to zoology. Within what limits must contingencies be allowed for? From that it is but a short stage to the study of climate not as an assemblage of averages but as a subject whose elucidation requires a veritable orchestra of contributory noises.

He who would thus go beyond the introductory text finds no very easy outlet. He cannot proceed under his own steam, and unless he has a rather odd mind the world-wide masses of observational material may prove astonishingly repellent. So much is gathered and so little is rendered digestible beyond the simplest stage. Even in England the reviewer has been repeatedly surprised by the utter ignorance displayed by many inquirers of the wholesome and palatable forage so easily obtained in the *Monthly Weather Report*.

With this in mind we rarely find anyone with the will and capacity to assemble for us not merely climatic material on a world-wide scale, but with regard to the whole sweep of geological time. It is no wonder that Dr. Brooks' "Climate through the Ages" has been acclaimed for over twenty years as a standard work whose international reputation is confirmed by repeated citation. In the first edition (1926) Dr. Brooks included in compact form the results of his early studies of the relationship between continentality and temperature, and the consequences of varying the extent of the Arctic ice as well as the extent and elevation of the land masses. With the aid of his fundamental training as a geologist he has done invaluable service in bringing together the results derived from a truly marvellous variety of observational material from oceanography

and geology, botany and archæology, backed by the informed grasp of meteorological principles which we have long known him to possess. And for long we have gone back to him for a guide to the extraordinary problems of climatic change, so succinctly summarised in that delightful list (in Appendix II) of the fifty or so diverse theories which have been put forward. For as our own evolution as a species in all probability owes more to climatic change than to any other environmental variable, it is no wonder that the grandeur of the problems presented by the Scandinavian erratics in Norfolk or the Jurassic flora of Spitsbergen remains for many of us surpassingly attractive. Moreover, he brings us forward to the historical period; from questions of Palæozoic glaciation we are swept through Chinese archives to the Napoleonic winters with fascinating ease.

That a new edition of this standard work should appear is opportune. The author has not made many changes; but in the light of more recent work he views sunspots with caution. As he justly says, his concept of glacial and non-glacial climates has now received general acceptance. The question that remains is why should the glacial climates develop at certain stages in the earth's history. It is well to observe how for a time many major problems of climatic change in the geological record were supposedly satisfied by a facile adoption of continental drift; and his review of the evidence may be commended.

Not the least interesting development in recent years has been the recognition by geophysicists such as Umbgrove that it is necessary to revive Brooks' scheme of rearrangement of the ocean currents, first published in the *Quarterly Journal**, as a possible explanation of the Upper Palæozoic glaciation, provoking though it remains. Dr. Brooks must have contemplated with no little pleasure the recognition by Sir George Simpson in 1934 that the eccentric position of glaciation in the northern hemisphere might well be explained by his geographical distribution of land and sea rather than by any needless and, according to some, unacceptable wanderings of the North Pole. The undeniable association of great ice ages with orogenic uplift remains, but we have still to solve the problem of multiple glaciation. Dr. Brooks may, in the past, have been criticised for his early readiness to bounce Scandinavia up and down, so to speak, to explain the several phases. He has apparently retreated from this view and justly reminds us of Sir George Simpson's elegant theory of multiple glaciation; but it is a pleasure to find (p. 377) that he still considers that the results of shifting of crustal loading may be important.

For serious complications are introduced into these arguments if we accept Professor Wager's view that the development of the Greenland ice-cap may have to be put back into the Miocene; this paper† appears to have been somewhat overlooked, but to the reviewer's knowledge has not been controverted. Some might therefore consider that the intermittent peripheral glaciation of Scandinavia and Laurentia during the Pleistocene can after all be explained by isostatic boundings following a long interval during which the seas were cooled. If so, we are confronted with the fact that we are living in an interglacial period, and with the problem of disposing of the high Polar ice-caps

*BROOKS, C. E. P.; The meteorological conditions during the glaciation of the present tropics, being some remarks on the climatological basis of Wegener's theory of continental drift. *Quart. J. R. met. Soc., London*, 52, 1926, p. 251.

†WAGER, L. R.; The form and age of the Greenland ice cap. *Geol. Mag., London*, 70, 1933, p. 145.

once formed; and this raises again the rate of dispersal of heat through the bottom of the oceans and elsewhere. It becomes evident why many regard this as one of the most desirable subjects of geophysical inquiry.

Dr. Brooks is understandably cautious with regard to "astronomical" theories of climatic change so ably restated in recent years by Professor Zeuner; that there is much to be said against such views is evident from other recent writers. We must all await the answer to many of these problems when the core-samples from the ocean bed obtained by the *Albatross* have been fully discussed. In regard to the oceans Dr. Brooks is quite invaluable for the breadth of the references he gives and for the stimulus he thus provides. For example, on pp. 72 and 79 he reminds us of the open "North Water" of Baffin's Bay; it brings to mind at once a possible explanation of the relatively mild ice-age climate of the Lofotens, allowing the survival of plants at a time when even the greater part of distant Ireland lay under ice. Elsewhere he has re-interpreted the African data in a way which will be interesting to all students of that continent; reference to Nilsson's more recent work might have been added. With regard to Greenland, recent Danish work points to the effect of drought as well as cold in the mediæval Norse economy.

Progress in recent years has been rapid and, in the light of later work, Dr. Brooks might have added more to the chapter on climatic fluctuations in the historical period, having regard, for example, to the later results of the pollen-analysts. He pays relatively little attention to the events of the late-glacial epoch and it is now evident from the Windermere lake deposits and elsewhere that one of the most important climatic fluctuations to explain is the prolonged "Allerød oscillation". This relatively settled warmer phase followed that period of rapid waning of the Scandinavian ice which according to Mannerfelt was demonstrably due to increased storminess; and in turn the subsequent post-Allerød climatic recession cannot practicably be associated with changes in the extent of land and sea. Estimates of the mean temperature of subsequent post-glacial periods in Denmark have recently been contributed by Iversen* and might have been added, as they give a valuable index of the range of variation. The development of Pettersson's theory of tide-generating force (p. 369) offers a welcome indication of the way in which sudden variations in the extent of the arctic ice might arise. Can they in any way be associated with the curious interval of about 900 years between the recurrence horizons in the peat bogs, recently discussed by Dr. Verona Conway? In this connexion his bold and attractive diagram on p. 361 will give many food for thought.

In the historical period more account might have been taken of the recent work of Thorarinsson, who has shown that the Icelandic glaciers reached their maximum extent in historical times much later than (p. 303) the first half of the fourteenth century. This statement is amended in part on p. 375, but Thorarinsson has now put the greatest advances in the eighteenth or nineteenth century. On the same page it might be questioned whether any temperature change likely to have occurred in the sixteenth century would allow European glaciers to be "frozen to the ground". That there should be some delay between the accumulation of heavy snowfalls and catastrophic glacier advance is understandable; how long, we do not yet know.

*IVERSEN, J.; *Viscum, Hedera and Ilex as climate indicators. Geol. Fören. Stockh. Förh., Stockholm, 66, 1944, p. 463.*

Dr. Brooks points (p. 372) to the great storm floods in the North Sea coming before the maximum of Pettersson's tide-generating force. In the light of recent studies can we not also ascribe them to the displacement of deep lows towards the south Norwegian coast, which might in turn owe something to the contemporary spread of the Greenland ice? These minor problems of the "historical" phase appear at first to be insignificant against the vast sweep of Dr. Brooks' earlier chapters, but we are aware how often the explanation of the larger events may be sought in the processes we know to have been operative on the smaller scale, as in the "little ice age".

Some may think that Dr. Brooks is a little discouraging in his attitude to "chance variations" of the vigour of the atmospheric circulation (pp. 66 and 377)—"changes which may have no external cause". Far be it from our students of high-altitude radiation to be distracted from trying to prove that they hold a master-key over-ruling those terrestrial variables which the geographer is wont to find so attractive. There is nevertheless new hope for the earth-bound field-worker as the glaciologists and botanists have shown; and Dr. Brooks has demonstrated what a fascinating variety of evidence must be brought together before we can build up a coherent scheme of the variations to which the world's climate has been subject. He can indeed look with pride on his own contributions. We can now appreciate how some of his earlier ideas are finding renewed support, and with what wisdom he himself reminds us that there have been other contributors whose concepts with regard to the effect of volcanic dust or of carbon dioxide may yet be shown to have some validity in regard to climatic change.

Scientists in many fields owe a great debt to Dr. Brooks for a stimulating conspectus; and if even he, with his magnificent sweep, has not quite overtaken some of the most recent literature in a gigantic field, he can reflect on how much he himself has done to arouse interest in these problems through his original work and the invaluable summaries he has provided. Few indeed can be found capable of thinking in such world-wide terms, and it is to be hoped that he will be able to take up again some of the implications of his earlier work. Geologists and geographers will continue to find his book indispensable for its material and exemplary in its comprehension and critical handling of data; meteorologists retreating from the synoptic chart will be encouraged to renew their study of the fundamental physics of the atmosphere; and many more general readers will find their questions answered. The book is well produced; minor errors in the first edition (*e.g.* Fig. 22) have been corrected. A small error arises in the index where under "Matthes" a reference on p. 316 is given which does not there exist. On pp. 307-8 it might be added that the Towneley rainfall measurements are available from 1677-1703.

GORDON MANLEY

Present climatic fluctuation, by H. W. Ahlmann, and *Problem of the Great Ross Barrier*, by F. Debenham. *Geographical Journal*, London, **112**, 1949, pp. 165-95 and 196-218.

Most articles in the *Geographical Journal* are of meteorological interest. In the April number there are two of very special interest. These are Prof. Ahlmann's paper on the "Present Climatic Fluctuation" and Prof. Debenham's on the "Problem of the Great Ross Barrier".

Prof. Ahlmann's paper is probably the most comprehensive general survey in existence of the climatic changes of the past hundred years, and a study of it is recommended to all meteorologists. The evidence of a general warming and increasing dryness is very impressive. In Greenland the change is so marked that the Danish Prime Minister was able to say, in November 1948, that a new era had begun for that country.

Prof. Debenham discusses many features of the Ross barrier ice sheet but the main subject of discussion is whether it melts or freezes at the bottom in the outer parts where it is known to be over the sea. Arguing from the fact that marine deposits are found on top of the sheet he concludes that it is fed by freezing at the bottom.

G. A. BULL

OBITUARIES

Mr. Albert Wilson, who died on May 15 at the age of 86, became interested in weather recording in 1872 when, at the age of 9, he started to measure rainfall under the supervision of his father. He sent records for publication in *British Rainfall* from 1892 until his death, the observations being made first at Bradford and subsequently at Ilkley, Garstang, Sedbergh, Tynygroes (Caernarvon) and finally at Carnforth.

With his brother, Mr. Sydney Wilson, he set up several monthly gauges on mountain sites at the turn of the century and maintained some of these records for 25 years.

Mr. Wilson was a Fellow of the Royal Meteorological Society and of the Linnean Society. He was a keen botanist and author of "The flora of Westmoreland", "The altitudinal range of British plants" and a number of papers on botanical and meteorological subjects.

It is a pleasure to learn that his interest in rainfall observation is shared by his son, Mr. Howard Wilson, who is continuing the record at Priest Hutton, near Carnforth.

Dr. G. Ainslie Johnston set up a rain-gauge at Ambleside in February 1895 and made regular observations until his death on June 4, 1949, a period of 54 years. Few observers have maintained a homogeneous series of observations for so long. The records have been published in the annual volumes of *British Rainfall*.

ERRATUM

July 1949, facing PAGE 201; beneath the photograph, insert "*Reproduced by courtesy of the U.S. Navy.*"

WEATHER OF JUNE 1949

Mean pressure was 1020 mb. or slightly over at the Azores, in the southern parts of England and Ireland, in Belgium and northern France, and northward of Scandinavia, and was between 1005 and 1010 mb. over an area nearly 1,000 miles in diameter south of Greenland. It was about 1015 mb. over most of North America, but below 1010 mb. in the north-west of Mexico and over part of central Canada. Deviations from the normal were small in western Europe and North America, but were between -5 and -8 mb. over most of the area of low pressure south of Greenland, and between +6 mb. and +8 mb. off the north-east coast of Greenland.

The weather over the British Isles was dry and warm with a large excess of sunshine. At Renfrew and Stornoway it was the sunniest June on record, while at Leuchars the total sunshine equalled the previous record of 1940. Rainfall was well below the average preliminary values for the percentages of the average for the period 1881-1915 being 30 over England and Wales, 59 over Scotland and 43 over Northern Ireland.

During the first four days depressions were situated off the west of Scotland, while troughs of low pressure moved north-east over the British Isles; rain fell in most places and thunderstorms occurred, the latter being rather widespread on the 1st and 2nd. Temperature during this period was rather low. On the 5th a wedge of high pressure moved east across the country and fair, sunny weather prevailed, though rain occurred locally in the west and north later. Thereafter a depression moved east-north-east off our northern seaboard and an associated trough moved east over the British Isles giving gales in the northern half of the country and slight rain, except in south-east and east England. The wind gusted up to 52 kt. at Durham and 48 kt. at Tiree and at Bidston Observatory on the 6th. On the 7th a complex area of low pressure moved across the country, giving scattered thunderstorms. On the 9th an anticyclone over Scotland moved east and was followed by a weak trough of low pressure; fair weather prevailed except in the north of Scotland. On the 10th further rain fell in the northern half of the country, but fair weather persisted in southern England. On the 12th and 13th a weak trough of low pressure moved south-east over the British Isles giving some rain in many areas but the rain did not reach the south of England until the 13th.

Subsequently an anticyclone moved north-east to the Faeroes where it remained almost stationary, with a wedge extending southward over the British Isles, until the 26th; it then moved slowly east in front of a weak trough off our north-west seaboard. Dry, sunny, rather cool weather prevailed until the 20th, when temperature rose, the weather continuing sunny and dry. On the 26th a new anticyclone off our south-west coasts moved slowly east, while a trough approached our western coast and subsequently moved very slowly east. Fair, very warm weather prevailed over much of the country, though some rain fell at times in Scotland and Ireland; rain was recorded in northern England also on the 28th. By the 29th pressure was high in an anticyclone over Scotland; this system moved rather quickly north-east and, in its rear, another trough moving north-east caused further rain in Scotland and Ireland on the night of June 30-July 1.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	90	32	+1·8	30	—6	125	50
Scotland ..	84	28	+1·2	59	—8	137	47
Northern Ireland ..	83	36	+2·5	43	—6	147	50

RAINFALL OF JUNE 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	·71	35	<i>Glam.</i>	Cardiff, Penylan ..	·65	26
<i>Kent</i>	Folkestone, Cherry Gdn.	·61	31	<i>Pemb.</i>	St. Ann's Head ..	·24	11
"	Edenbridge, Falconhurst	·57	26	<i>Card.</i>	Aberystwyth ..	·49	20
<i>Sussex</i>	Compton, Compton Ho.	·81	33	<i>Radnor</i>	Tyrmynydd ..	·88	27
"	Worthing, Beach Ho.Pk.	·77	44	<i>Mont.</i>	Lake Vyrnwy ..	1·41	43
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	·39	21	<i>Mer.</i>	Blaenau Festiniog ..	2·49	38
"	Bournemouth ..	·39	19	<i>Carn.</i>	Llandudno ..	·42	22
"	Sherborne St. John ..	·30	14	<i>Angl.</i>	Llanerchymedd ..	·64	27
<i>Herts.</i>	Royston, Therfield Rec.	·96	43	<i>I. Man.</i>	Douglas, Borough Cem.	·38	16
<i>Bucks.</i>	Slough, Upton ..	·27	13	<i>Wigtown</i>	Port William, Monreith	·72	31
<i>Oxford</i>	Oxford, Radcliffe ..	·46	21	<i>Dumf.</i>	Dumfries, Crichton R.I.	·87	34
<i>N'hant.</i>	Wellingboro', Swanspool	·50	24	"	Eskdalemuir Obsy. ..	1·31	42
<i>Essex</i>	Shoeburyness ..	·62	35	<i>Roxb.</i>	Kelso, Floors ..	·87	41
<i>Suffolk</i>	Campsea Ashe, High Ho.	·49	26	<i>Peebles</i>	Stobo Castle ..	1·08	46
"	Lowestoft Sec. School ..	·36	20	<i>Berwick</i>	Marchmont House ..	1·15	50
"	Bury St. Ed., Westley H.	·77	37	<i>E. Loth.</i>	North Berwick Res. ..	1·33	80
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·04	48	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	1·01	51
<i>Wilts.</i>	Bishops Cannings ..	·47	19	<i>Lanark</i>	Hamilton W. W., T'nhill	1·15	52
<i>Dorset</i>	Creech Grange ..	·47	20	<i>Ayr</i>	Colmonell, Knockdolian	·81	32
"	Beaminster, East St. ..	·45	20	"	Glen Afton, Ayr San ..	1·00	33
<i>Devon</i>	Teignmouth, Den Gdns.	·82	43	<i>Bute</i>	Rothsay, Arden Craig	1·29	42
"	Cullompton ..	·93	44	<i>Argyll</i>	L. Sunart, Glenborrodale	3·09	96
"	Barnstaple, N. Dev. Ath.	·49	22	"	Poltalloch ..	1·60	52
"	Okehampton, Uplands	·58	21	"	Inverary Castle ..	1·71	43
<i>Cornwall</i>	Bude School House ..	·32	16	"	Islay, Eallabus ..	1·08	41
"	Penzance, Morrab Gdns.	·75	34	"	Tiree ..	1·33	52
"	St. Austell, Trevarna ..	1·49	57	<i>Kinross</i>	Loch Leven Sluice ..	1·49	68
"	Scilly, Tresco Abbey ..	·41	24	<i>Fife</i>	Leuchars Airfield ..	·92	55
<i>Glos.</i>	Cirencester ..	·58	24	<i>Perth</i>	Loch Dhu ..	2·38	57
<i>Salop.</i>	Church Stretton ..	·59	23	"	Crieff, Strathearn Hyd.	1·31	50
"	Cheswardine Hall ..	·67	27	<i>Perth</i>	Pitlochry, Fincastle ..	1·63	78
<i>Worcs.</i>	Malvern, Free Library	·42	18	<i>Angus</i>	Montrose, Sunnyside ..	1·35	81
<i>Warwick</i>	Birmingham, Edgbaston	·25	11	<i>Aberd.</i>	Braemar ..	1·26	64
<i>Leics.</i>	Thornton Reservoir ..	·57	26	"	Dyce, Craibstone ..	1·93	103
<i>Lincs.</i>	Boston, Skirbeck ..	·79	43	"	Fyvie Castle ..	1·25	60
"	Skegness, Marine Gdns.	·87	48	<i>Moray</i>	Gordon Castle ..	1·18	58
<i>Notts.</i>	Mansfield, Carr Bank ..	·76	34	<i>Nairn</i>	Nairn, Achareidh ..	1·09	62
<i>Derby</i>	Buxton, Terrace Slopes	1·94	60	<i>Inv's</i>	Loch Ness, Foyers ..	1·21	55
<i>Ches.</i>	Bidston Observatory ..	·89	40	"	Glenquoich ..	2·87	58
<i>Lancs.</i>	Manchester, Whit. Park	·83	31	"	Fort William, Teviot ..	2·55	72
"	Stonyhurst College ..	1·13	37	"	Skye, Duntuilim ..	2·08	80
"	Blackpool ..	·51	23	<i>R. & C.</i>	Ullapool ..	1·53	67
<i>Yorks.</i>	Wakefield, Clarence Pk.	·47	22	"	Applecross Gardens ..	2·44	85
"	Hull, Pearson Park ..	·41	20	"	Achnashellach ..	2·38	63
"	Felixkirk, Mt. St. John	·81	37	"	Stornoway Airfield ..	1·08	49
"	York Museum ..	·57	28	<i>Suth.</i>	Lairg ..	1·11	62
"	Scarborough ..	·73	40	"	Loch More, Achfary ..	2·71	73
"	Middlesbrough ..	·53	28	<i>Caith.</i>	Wick Airfield ..	1·40	78
"	Baldersdale, Hury Res.	·75	32	<i>Shetland</i>	Lerwick Observatory ..	1·03	58
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	1·49	71	<i>Ferm.</i>	Crom Castle ..	1·54	57
"	Bellingham, High Green	·82	36	<i>Armagh</i>	Armagh Observatory ..	·98	39
"	Lilburn Tower Gdns. ..	·84	41	<i>Down</i>	Seaforde ..	·50	18
<i>Cumb.</i>	Geltsdale ..	·66	24	<i>Antrim</i>	Aldergrove Airfield ..	·58	24
"	Keswick, High Hill ..	·80	27	"	Ballymena, Harryville ..	1·45	50
"	Ravenglass, The Grove	·65	25	<i>L'derry</i>	Garvagh, Moneydig ..	1·17	46
<i>Mon.</i>	Abergavenny Larchfield	·71	29	"	Londonderry, Creggan	1·81	64
<i>Glam.</i>	Ystalyfera, Wern House	·72	19	<i>Tyrone</i>	Omagh, Edenfel ..	1·31	46

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, FEBRUARY 1949
(See Notice on p. 237)

STATIONS	PRESSURE		TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE					
	Mean of day M.S.L.	Diff. from normal	Absolute			Mean values					Total	Diff. from normal	Days	Daily mean	Per- centage of possible			
			Max.	Min.	°F.	Max.	1 2	Min. and normal								°F.	Diff. from normal	Wet bulb
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	in.	in.	hr.	%				
1027.5	+12.5	55	48.7	34.9	41.8	38.6	+1.1	89	4.0	0.88	-0.66	9	3.8	38				
1025.7	+5.7	67	62.6	52.4	57.5	53.0	+1.7	79	3.9	2.38	—	5	6.6	61				
1022.7	+6.6	65	58.6	48.3	53.5	52.5	-1.8	78	5.3	2.50	—	7	5.5	51				
1013.6	+1.1	81	78.3	62.9	70.6	63.3	+5.3	96	6.9	0.83	-1.91	8	—	—				
1011.0	—	94	88.4	72.9	80.7	73.3	—	86	2.1	0.00	—	0	—	—				
Lagos, Nigeria	1010.5	+0.8	97	93.0	71.4	82.2	-0.3	74	4.3	0.08	—	1	5.1	43				
1004.5	—	97	89.1	61.0	75.2	54.1	-2.5	17	1.9	0.00	-0.02	0	7.2	61				
Kaduna, Nigeria	1012.5	+0.4	95	85.1	66.5	75.8	+1.6	70	1.6	1.58	-6.50	10	7.1	56				
Chileka, Nyasaland	1011.4	+0.3	88	80.6	61.6	71.1	+0.4	86	5.5	3.18	-5.44	13	7.1	56				
Lusaka, Rhodesia	1012.3	+0.2	87	78.4	58.3	68.3	0.6	73	4.0	4.75	-2.14	9	6.9	54				
Salisbury, Rhodesia	1013.7	+0.3	95	82.6	62.4	72.5	+2.2	62	3.1	0.20	-0.38	3	—	—				
Cape Town, S. Africa	—	—	87	79.2	55.8	67.5	—	70	4.0	1.90	—	11	8.9	—				
Palmfontein, S. Africa	1012.2	-1.3	96	85.4	60.6	73.0	+1.8	73	0.7	0.03	-0.96	1	9.5	83				
Mauritius	1012.0	-0.7	101	85.4	68.3	76.9	+1.2	74	1.0	0.00	-0.03	0	9.8	85				
Calcutta, Alipore Obsv.	1012.3	-0.6	96	88.3	68.3	78.3	1.0.6	81	3.3	0.00	-0.30	0	10.0	85				
Bombay	1010.7	0.1	93	88.2	69.8	79.0	-1.4	89	3.5	0.14	-1.80	2	9.1	76				
Madras	1009.2	-1.0	93	88.3	74.1	81.2	+1.0	79	6.1	4.94	-1.68	14	4.7	—				
Colombo, Ceylon	1017.3	-1.3	77	49	67.8	62.7	+3.6	81	—	4.96	+3.13	8	4.7	41				
Singapore	1009.8	-4.1	92	78.8	65.0	71.9	+0.6	70	4.7	6.55	+2.35	10	7.0	52				
Hongkong	1010.5	-4.0	88	73.6	53.9	63.7	-3.9	60	4.1	2.43	+0.72	7	7.8	38				
Sydney, N.S.W.	1012.9	-1.4	82	74.5	57.8	66.1	7.9	55	5.0	2.50	+1.78	8	6.9	52				
Melbourne	1012.9	-1.4	100	87.7	64.7	76.2	+2.1	46	2.0	0.27	-0.18	1	9.7	74				
Adelaide	1011.8	-0.6	96	85.9	60.1	73.0	-3.2	52	3.3	0.92	+0.97	5	—	—				
Perth, W. Australia	1009.8	-2.7	92	85.2	70.8	78.0	+1.5	73	5.8	6.81	+0.47	13	6.1	47				
Coalgardie	1006.4	-6.8	73	65.4	48.4	56.9	-5.4	56	5.9	1.14	-0.34	10	7.1	31				
Hobart, Tasmania	1011.6	-2.2	77	70.5	56.4	63.5	+2.3	78	5.7	1.29	-1.85	10	6.7	49				
Wellington, N.Z.	1008.9	+1.1	89	71	74.7	80.1	-0.2	83	5.5	7.23	-3.49	21	6.6	52				
Suva, Fiji	1008.5	+0.3	89	86.5	74.1	80.3	0.0	80	5.8	8.51	-6.38	20	5.9	47				
Apia, Samoa	1016.6	+1.3	90	87.5	67.1	77.5	+1.0	73	1.7	0.02	-0.58	1	9.0	78				
Kingston, Jamaica	—	—	87	83.0	71.0	78.5	+1.1	74	4.4	2.45	-0.33	18	—	—				
Grenada, W. Indies	1019.4	+1.4	53	46.5	22.1	29.3	+8.2	80	5.3	2.83	+0.45	12	3.8	36				
Toronto	1021.1	-0.7	24	3.5	-15.8	-6.1	-6.2	—	3.1	1.07	+0.34	14	4.2	42				
Winnipeg	1018.3	+4.4	47	31.3	14.2	22.7	+2.8	85	4.5	4.11	+0.21	11	4.8	46				
St. John, N.B.	1010.8	-5.8	55	43.0	28.7	35.9	4.6	88	5.4	6.86	+3.00	18	3.5	34				
Victoria, B.C.	—	—	—	—	—	—	—	—	—	—	—	—	—	—				

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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DR. JOHNSON AND THE WEATHER

By D. L. BOWEN

The everyday discussion of weather is by no means a twentieth-century prerogative, for it is an historic fact that the England of Samuel Johnson's day was keen to cultivate the habit; indeed, it was in great vogue in the London of the 1770's—and how the worthy Dr. Johnson hated it.

It is hardly surprising, feeling as he did, that Dr. Johnson time and time again fell back on his superb and seemingly limitless vocabulary to quash any desire on the part of his friends to "talk" weather. We can consider that it was Johnson's profundity which caused him to regard casual weather observations as "small talk", but whatever the reasons it seems that the learned gentleman would allow no compromise; he would be as withering as his commanding presence and brilliant fluency would allow.

Boswell evidently was an aspiring amateur meteorologist, and, though frequently rebuked by his master, was never permanently cheated of his interest in weather. In his "Life of Dr. Johnson" he recorded some amusing weather repartee that took place between Johnson and himself; there is, for example, the entry for July 1763: ". . . On the 14th we had another evening by ourselves at The Mitre. It happening to be a very rainy night, I made some common-place observations on the relaxation of nerves and depression of spirits which such weather occasioned; adding, however, that it was good for the vegetable creation. Johnson, who, as we have already seen, denied that the temperature of the air had any influence on the human frame, answered with a smile of ridicule, 'Why yes, Sir, it is good for vegetables, and for the animals who eat those vegetables, and for the animals who eat those animals.' This observation of his aptly enough introduced a good supper; and I soon forgot, in Johnson's company, the influence of a moist atmosphere."

To leave his readers in no doubt whatsoever, Boswell, on a later occasion, tells another story. "There was", he declares, "no information for which Dr. Johnson was less grateful than for that which concerned the weather. . . . If any one of his intimate acquaintance told him it was hot or cold, wet or dry, windy or calm, he would stop them by saying, 'Poh! poh! you are telling us that of which none but men in a mine or a dungeon can be ignorant. Let us bear with patience, or enjoy in quiet, elementary changes, whether for the better or the worse, as they are never secrets'."

There were times, however, when Samuel Johnson's lack of compromise must have been thoroughly upsetting. On one occasion both Boswell and Johnson had enjoyed to the full an exceptionally fine day in July 1763. It had been spent on the Thames; both had enjoyed the day's sculling, although Boswell's resistance was weakened on account of his having sat up the whole of the previous night. Having overstayed the visit paid to Greenwich, they were exposed to radiation cooling as the return journey by river was undertaken, and doubtless the cold was accentuated for anyone negotiating an open boat. Johnson's "robust frame was not in the least affected" by the diurnal cooling, and Boswell, having succumbed to shivering, was sternly rebuked as though his behaviour "had been a paltry effeminacy."

Yet it would not be altogether fair to say that Johnson was not weather conscious. He found time to pause and admire the "silver flood" of the Thames as it flowed past Greenwich—and the "silver flood" of an English river cannot be divorced from the "silver flood" of English rain. No, evidence does not show him making fun of weather as such. His war was against those who, in saying the obvious things about the weather whenever the opportunity presented itself or whenever there was a gaping chasm to be filled pending the resumption of a flow of conversation, would deliberately and inevitably lose their originality. It was imaginative laziness, a thing he could not tolerate.

Even more infuriating to the very hard-working Dr. Johnson was the bodily laziness that his contemporaries would attribute to the weather rather than to themselves. In such cases many would wholeheartedly agree with the severity of Johnsonian censures, but, justifiable or not, they are most stimulating and often amusing: take, for example, the following pronouncements—they could almost be described as "laws":—

"This dependence of the soul upon the seasons, those temporary and periodical ebbs and flows of intellect, may, I suppose, justly be derided as the fumes of vain imagination. . . . The author that thinks himself weather-bound will find . . . that he is only idle or exhausted. But while this notion has possession of the head, it produces the inability which it supposes. . . ." Cleverly expounded, one is made to feel that such invective is aimed at more than just authors who find they are incommoded by unfavourable seasonal or diurnal changes of weather. One feels that none can claim exemption from Dr. Johnson's scolding, be he business executive, farmer, newspaper editor, or meteorologist.

But anyone who takes advantage of prevailing—or anticipated future—weather conditions to harness, as it were, such phenomena to the task in question, is a man after Johnson's own heart. Boswell verifies this:—

"He records of himself this year, 'Between Easter and Whitsuntide, having always considered that time as propitious to study, I attempted to learn the Low Dutch language.' It is to be observed, that he here admits an opinion of the human mind being influenced by seasons. . . ."

Boswell was obviously thinking of the cutting remarks in an edition of the *Idler*, words that he knew had emanated from his master: "Those that laugh at the portentous glare of a comet, and hear a crow with equal tranquillity from the right or left, will yet talk of times and situations proper for intellectual performances." But the weight of Dr. Johnson's pronouncements on this

subject of weather will verify that his warfare left unscathed those who adjusted their time-tables according to the prevailing meteorological conditions so that they might thereby be more effective.

There is an aspect of the Johnson of later years that does not compare favourably with the Johnson of 1760—or even 1770. He finds he himself is indulging in that easily acquired habit, that same luxury that he denied to others—the universal practice of observing and commenting on the weather. The reason, however, requires little search, for in January 1784 he writes to his friend to inform him of his sufferings:—

“ I was seized with a spasmodic asthma so violent that with difficulty I got to my own house, in which I have been confined eight or nine weeks, and from which I know not when I shall be able to go even to church. . . . My nights are very sleepless and very tedious. And yet I am extremely afraid of dying.

“ My physicians try to make me hope, that much of my malady is the effect of cold and that some degree at least of recovery is to be expected from vernal breezes and summer suns. If my life is prolonged to autumn I should be glad to try a warmer climate. . . .”

How tragically ironical! The cause of Johnson's illness was presumably the weather, the result was his own extensive weather talk, and the remedy—a suggested exposure to weather of a different kind. The picture of the learned doctor takes new colour. “ I am reduced to think,” he says, “ and am at last content to talk of the weather.”

On this candid admission Dr. Johnson's past strictures must be forgiven, and the more especially when he postscripts these remarks by quoting against himself the familiar proverb, “ Pride must have a fall.”

RELATION BETWEEN UPPER WIND STRUCTURE AND RAINFALL AT FRONTS

By A. E. PARKER B.Sc., A.M. Tech. I.

The fact that upslope (or downslope) motion may occur at fronts is not usually used directly in forecasting, but the upslope motion is deduced from the weather and clouds associated with the front. This method of forecasting, therefore, does not deal with physical processes but is merely statistical in character. The ideal method of forecasting would be to use physics to indicate when and where upslope motion will occur and then to deduce the resulting weather. However, this method is not possible at present and, indeed, it is by no means certain that it will ever become possible.

The object of this note is to show that upslope motion at fronts can be detected by using the results of upper wind soundings, and can be taken directly into account in forecasting. The writer has been using the technique outlined in this note for the last two years or so and has found the method of great help in forecasting. By using the method, the forecaster not only obtains a very clear picture of wind structure at fronts but it sometimes enables outbreaks of rain, ahead of apparently weak warm fronts and behind cold fronts, to be forecast where none previously existed.

It is believed that the method will be new to the majority of forecasters in the British Isles.

Vertical wind structure through a warm front.—Suppose that we have an upper wind sounding which passes through a warm-front surface, and we wish to examine the upslope (or downslope) motion, if any, which is occurring. Upper winds from the sounding are plotted on a hodograph and a line is drawn through the origin of the hodograph parallel to the direction of the surface warm front at the point nearest to the upper wind station. The wind hodograph has been described frequently in the meteorological press during recent years and probably needs no introduction to readers of this magazine. However, the examples should make it and its use quite clear. Now the component of the wind at right angles to the surface direction of the front will be termed the “normal wind”. A little thought will show that,

(1) if the normal wind increases with height above the frontal surface then upslope motion must be occurring ;

(2) if the normal wind does not change with height then no upslope motion is occurring; and

(3) if the normal wind in the warm air decreases with height then the warm air is subsiding down the frontal surface. This type of motion is quite common at the top of the cold dome.

Vertical wind structure through a cold front.—The results of an upper wind sounding passing through a cold front surface are plotted on the hodograph in the same way as for a warm front but in this case,

(1) if the normal wind in the warm air decreases with height then upslope motion is occurring and we have a cold front with a wide band of rain and cloud behind it;

(2) if the normal wind does not change with height through the frontal surface then no upslope motion is occurring. It should not be deduced from this, however, that the front will give no precipitation. This type of front usually gives rain ahead of it due to convergence, and possibly instability, in the warm air; and

(3) if the normal wind increases with height through the frontal surface then the warm air is subsiding down the cold-front surface. The increase of wind with height in the warm air with this type of front is sometimes very marked indeed, and then the cold front gives no precipitation and only some strato-cumulus cloud ahead of it. These fronts are usually fast-moving fronts.

Upper wind soundings well ahead of cold fronts can be used to deduce the variation of the normal wind with height through the frontal surface. For example, the normal wind will commence to decrease with height at 500 mb. up to 200 miles ahead of a cold front having upslope motion of the warm air above it.

Frontal speed from the hodograph.—It is obvious that the speed of a warm front is the speed at which the cold air ahead of it is moving. Therefore, the speed of a warm front will be the normal wind at the base of the mixing zone and will be independent of height if the front is not changing its slope. The height of the base of the mixing zone can be obtained from a tephigram if a temperature sounding was made at the same time as the wind sounding; or, failing this, it can be obtained from the hodograph because the wind-shear vector for the winds at the top and bottom of the mixing zone is parallel to the surface front. Using this method to find the speed of a warm front the

writer has, at times, obtained the speed of the front to within one knot of the actual speed. The method is to be preferred to that of using the geostrophic scale and then guessing a fraction!

Practical examples of the use of the hodograph.—In the hodograph charts the radial scale is one division to 20 kt.; the winds at 900, 800 . . . mb. levels are represented by vectors from the origin to the points marked 9, 8 . . . respectively; the lines drawn on the hodographs represent the shear vectors between levels; and the arrow-heads at the ends of radii show the direction from which the corresponding wind is blowing.

Fig. 1—0600 G.M.T., August 8, 1946.—At 0600 a warm front was lying from $51^{\circ}\text{N.}5^{\circ}\text{W.}$ to the Channel Islands to $49^{\circ}\text{N.}3^{\circ}\text{E.}$ The hodograph of the Larkhill winds shows a normal wind increasing rapidly with height indicating upgliding motion of the warm air along the frontal surface. This front gave 0.40 in. of rain at Boscombe Down. The increasing normal wind was well marked to 400 mb. indicating that a thick layer of warm air was taking part in the upgliding motion. The intensity of rainfall from this front would have been expected to increase as the front moved north-eastwards and a deep layer

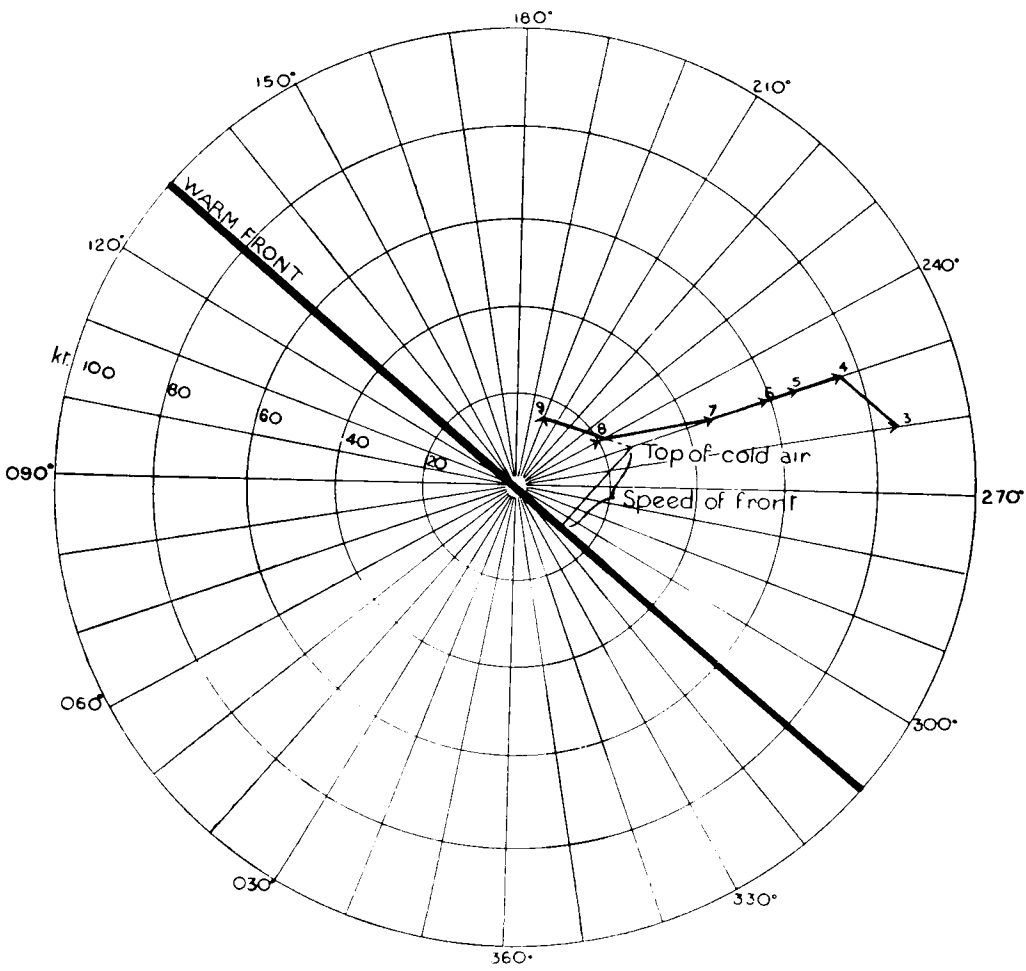


FIG. 1—HODOGRAPH OF WIND OVER LARKHILL,
0500, AUGUST 8, 1946

of air became saturated. Young waves on cold fronts must have a similar wind hodograph just ahead of them which accounts for the large rainfall often associated with small waves.

Now refer to the hodograph again. It will be seen that there is a well marked wind discontinuity between 800 and 700 mb., and by producing the wind-shear vector between the winds at 900 and 800 mb. to meet the 250° radial line we find that the speed of the front is 23 kt.

Fig. 2—1100 G.M.T., August 24, 1946.—A cold front at 1200 extended from Liverpool to Swansea to St. Eval. The hodograph of the Liverpool winds shows a normal wind decreasing with height from 800 to 500 mb. and therefore considerable rain would have been expected behind the front. Moderate to heavy rain fell as the front passed Shawbury (near Shrewsbury) followed by moderate to slight rain. The total rainfall at Shawbury from this front was 0.31 in., with 0.20 in. in three quarters of an hour. The pressure rose 6 mb. in three hours behind the front, which is interesting since rising pressure is not usually associated with moderate rainfall; but it is typical of this type of cold front due to marked advection of cold air.

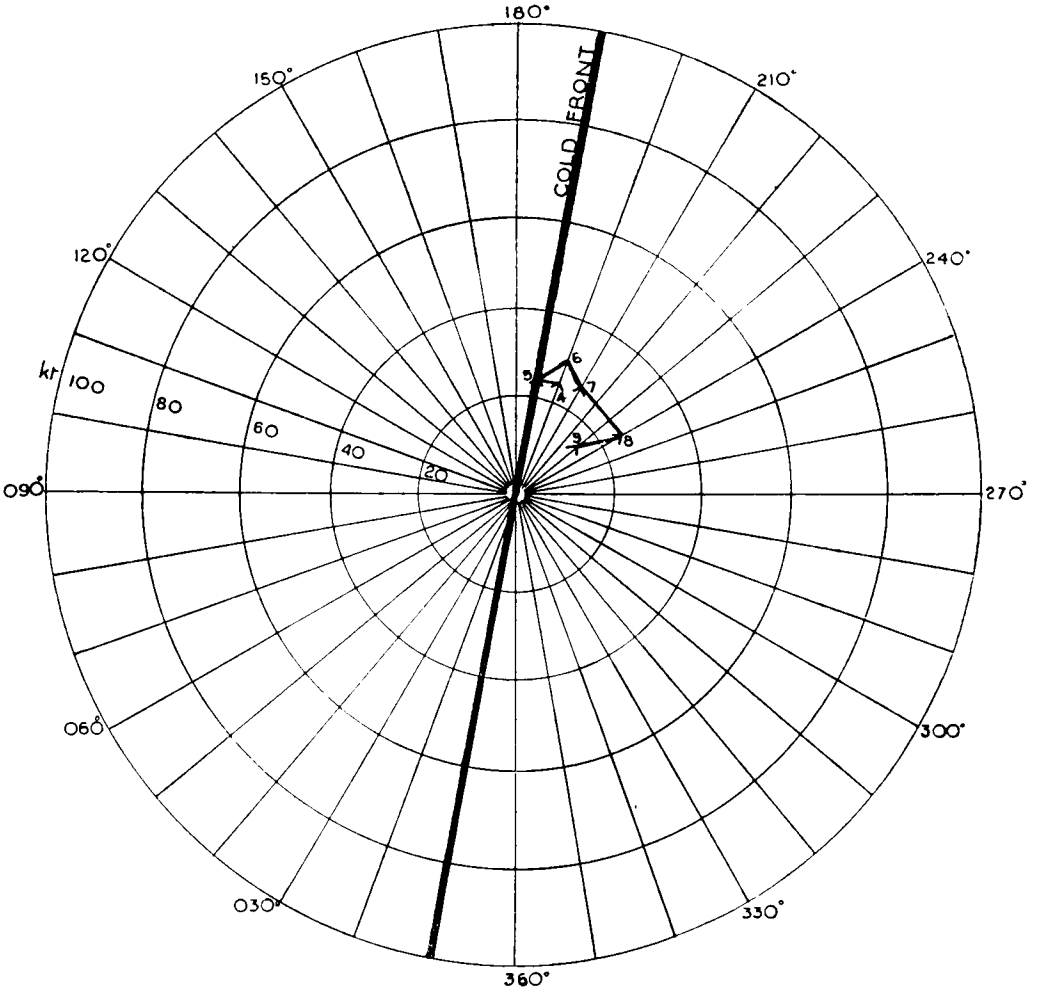


FIG. 2—HODOGRAPH OF WIND OVER LIVERPOOL,
1100, AUGUST 24, 1946

This example illustrates how an outbreak of rain behind a cold front can be forecast. If the warm air above a cold-front surface is moist and convectively unstable and the normal wind decreases with height through the frontal surface, then a widespread outbreak of moderate to heavy rain behind the front is almost certain and may extend up to 150 miles behind the cold front.

Fig. 3—0500 G.M.T., September 18, 1946.—At 0600 a warm front was 230 nautical miles south-west of Liverpool and lying north-west to south-east. This is a very interesting case. A forecaster, after looking at the 0600 chart, would almost certainly have said that the front would give continuous moderate rain as it moved north-eastwards across the country. The pressure had fallen 6·2 mb. at Shannon and Cork in south-west Ireland and 2·6 mb. in three hours at St. Eval in Cornwall. Furthermore, the upper winds veered and increased very rapidly with height indicating a marked temperature difference between the cold and warm air masses. The hodograph of the Liverpool winds suggests, however, that the upgliding motion at the front was confined to the layer 600 to 500 mb., *i.e.* a somewhat shallow layer above the frontal surface. The upper air over Liverpool above the frontal surface was also stable (*i.e.* had a lapse rate less than the saturated adiabatic) so that, taking all the facts into

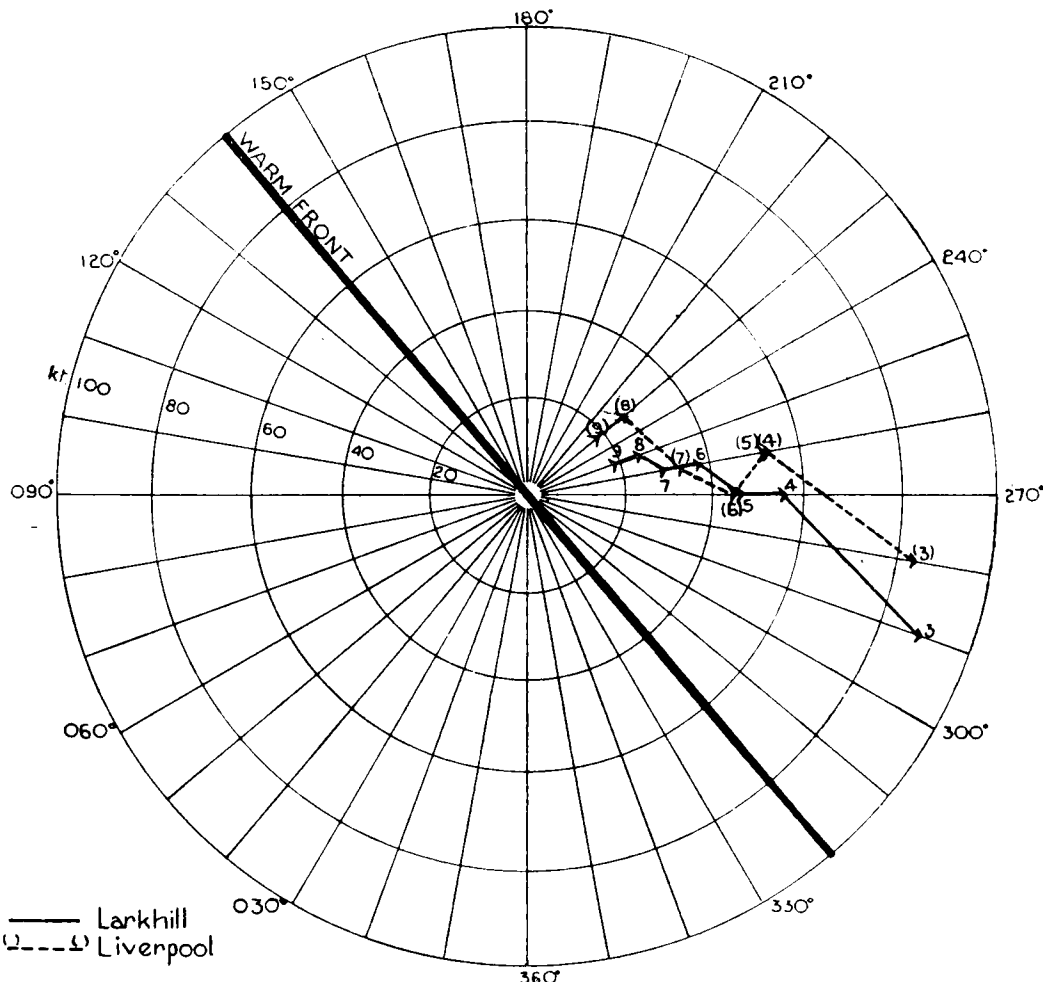


FIG. 3—HODOGRAPH OF WIND OVER LARKHILL AND LIVERPOOL,
0500, SEPTEMBER 18, 1946

consideration, one would not have expected much rain in the Liverpool area. This deduction was confirmed as only a trace of rain was recorded at Shawbury. Mr. C. K. M. Douglas* has pointed out that a dry patch of air is common to the lee of the Welsh hills due to orographic effects, but this does not affect the truth of the deductions made from the hodograph.

The hodograph of the Larkhill winds tells a different story, however, as the normal wind was increasing with height from 700 to 400 mb., and this suggests upgliding motion of the warm air through a rather deep layer, and hence the possibility of considerable rain. Stations in the south of England mainly reported continuous slight to moderate rain as the front approached. This was rather unusual as a warm front usually gives its greatest rainfall towards the tip of the warm sector.

The hodograph for the Liverpool winds shows a well marked wind discontinuity between 600 and 500 mb., so we may take the top of the cold air over Liverpool at 600 mb. The normal wind at this level is 35 kt. and this is

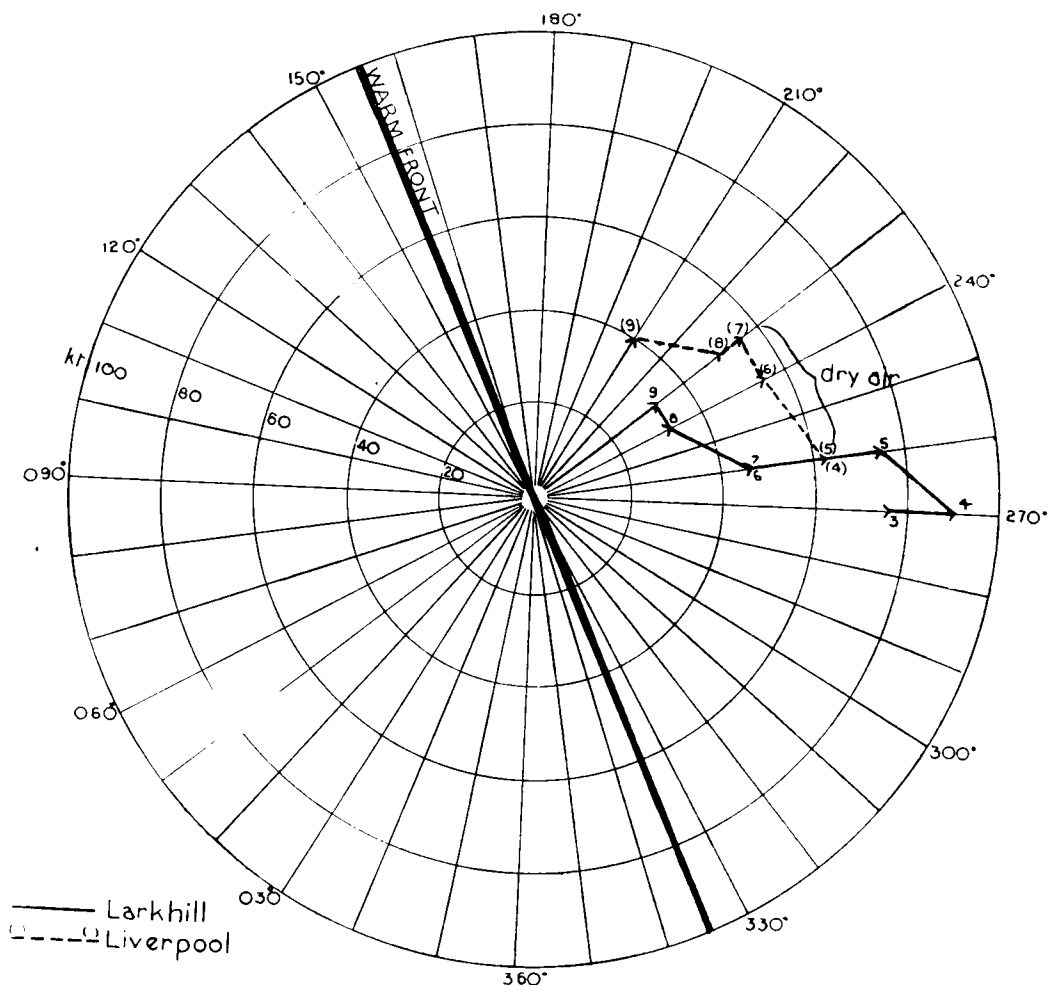


FIG. 4—HODOGRAPH OF WIND OVER LARKHILL AND LIVERPOOL,
1100, SEPTEMBER 18, 1946

*DOUGLAS, C. K. M.; Rainfall from above 6,000 ft. in relation to upper winds and fronts. *Quart. J. R. met. Soc., London*, **62**, 1936, p. 207.

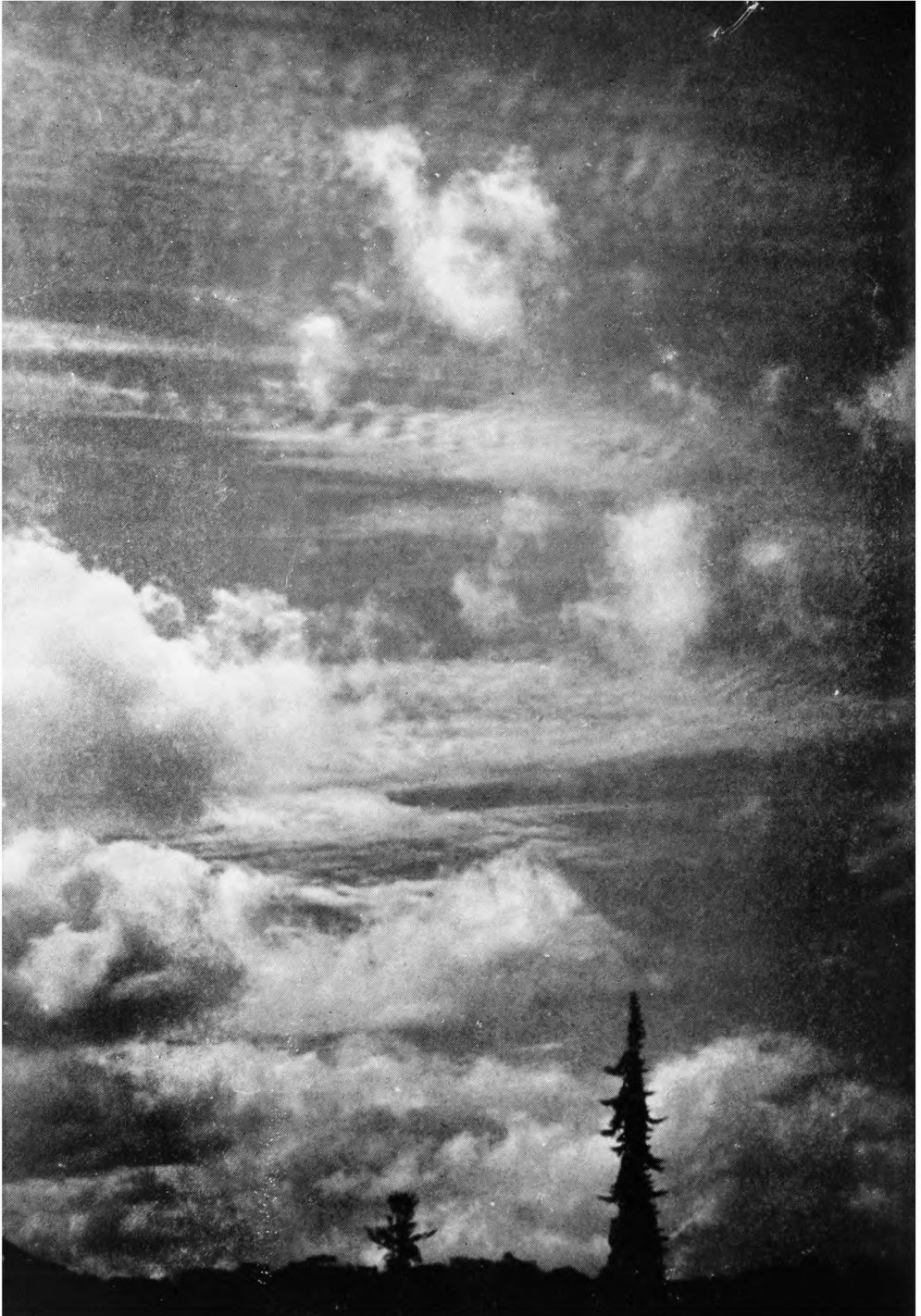


O.W.S. *Weather Watcher* AND *Weather Recorder* AT OCEAN WEATHER SHIPS' BASE
AT GREENOCK



OCEAN WEATHER SHIP ENSIGN

During the early days of their existence the British ocean weather ships flew the red ensign, but it has recently been considered more fitting that, being Government ships, they should fly a blue ensign defaced with an appropriate badge, as is customary for other vessels of similar category. The new ensign, as illustrated, was hoisted aboard the *Weather Watcher* and *Weather Recorder* at Greenock on March 7, 1949, the ceremony being performed by Provost Morris of Greenock



CIRRUS INDICATING RATHER UNSETTLED WEATHER AHEAD IN TANGANYIKA

This type of sky, which was photographed near Lushoto late on a November morning is rather persistent and may sometimes indicate a more unsettled period of weather ahead. On this particular occasion the deterioration may well have been associated with the "short" or "grass rains" which mark the southward migration of the potential zone of convergence which exists between the régimes of the two "monsoons" which affect Kenya and northern Tanganyika. Lushoto is situated among the Usambara Mountains about 50 miles inland from the coast of northern Tanganyika and connected by the Pare Mountains to Kilimanjaro 140 miles to the north-north-west

clearly the speed of the front. The Larkhill wind hodograph indicates a double wind discontinuity (a) from 500 to 400 mb. and (b) from 700 to 600 mb., probably indicating a double frontal structure. However, since the winds were only reported to the nearest whole ten degrees the double structure is not certain from the hodograph but was confirmed by the upper air ascents. It will be noticed that the normal wind at the 500-mb. level is 35 kt. which is the same as was given by the Liverpool winds.

Fig. 4—1100 G.M.T., September 18, 1946.—At 1200 the warm front considered in the previous example had moved to a position just west of Liverpool and just east of Larkhill. The actual speed of the front works out at 38 kt. as compared with the hodograph value of 35 kt. This discrepancy is no doubt due to the fact that the winds are reported at intervals of 50 mb. and the top of the cold air was somewhat higher than the value actually taken. The air above Liverpool was still very dry from 700 to 400 mb. with humidities varying from 37 to 20 per cent. Slight upslope motion of the warm air is suggested from 900 to 700 mb. Upgliding motion of the warm air along the front through a deep layer is suggested in south-east England by the Larkhill wind hodograph, as the normal wind was increasing markedly with height from 800 to 400 mb. Furthermore,

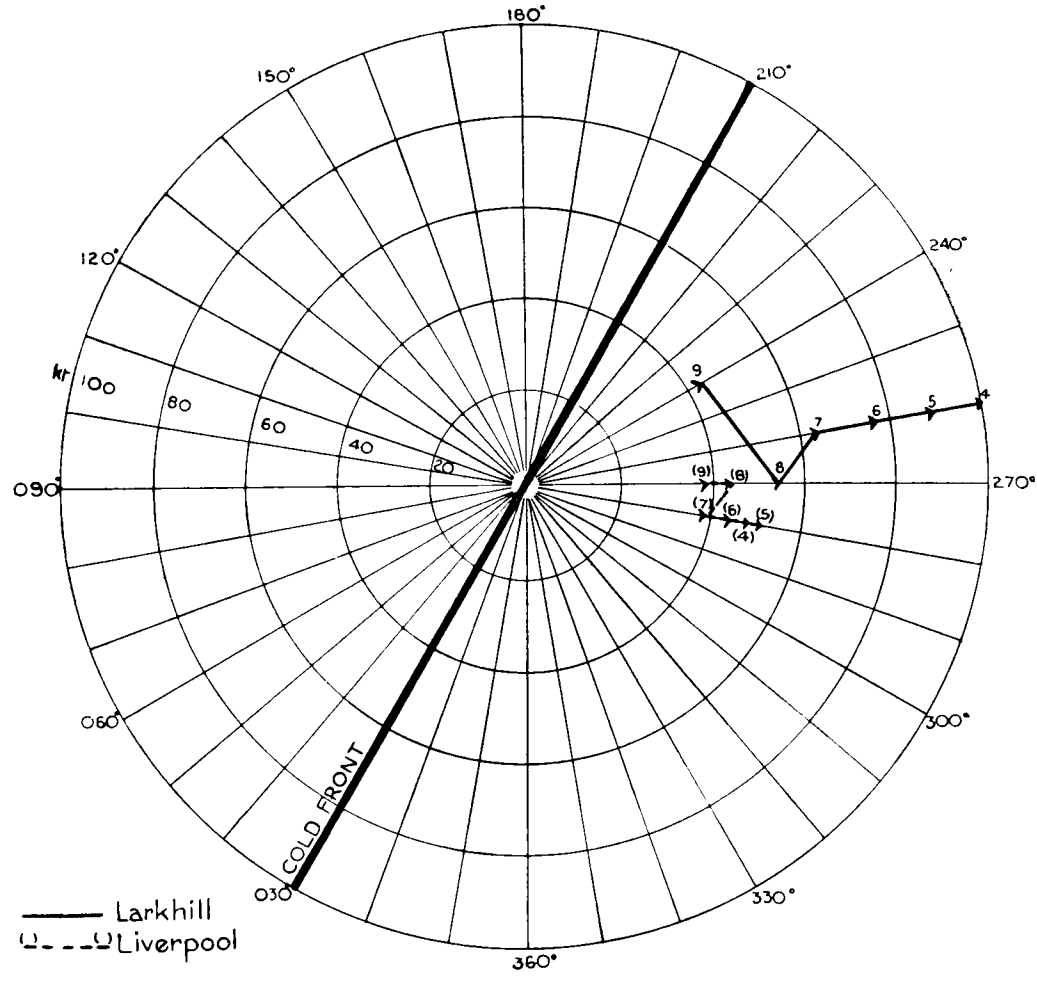


FIG. 5—HODOGRAPH OF WIND OVER LARKHILL AND LIVERPOOL, 1700, SEPTEMBER 18, 1946

the air was moist at all levels to 400 mb. showing that lifting must have taken place, and thereby confirming the deductions made from the 0500 hodograph.

Fig. 5—1700 G.M.T., September 18, 1946.—At 1800 a cold front extended from just east of Liverpool to Fairwood Common (near Swansea) and thence to the Scilly Isles. This cold front was the one associated with the warm front discussed in the two preceding examples. The normal winds on the Larkhill ascent increase with height at all levels and the air was very dry above 700 mb. A normal wind increasing with height through a cold-front surface indicates subsidence of the warm air and hence dryness. The Liverpool wind hodograph indicates a normal wind increasing with height except in the layer 800 to 700 mb. and this suggests the possibility of a layer of cloud at this level. It is worth noting here that a mere inspection of the hodograph frequently enables the moist and dry layers to be located. In fact, on one occasion in Germany, it was possible to obtain from the hodograph the height and thickness of a medium cloud sheet only about two to three thousand feet thick.

Fig. 6—0500 G.M.T., November 23, 1946.—At 0600 a warm front was 315 nautical miles west-south-west of Larkhill, which would give the top

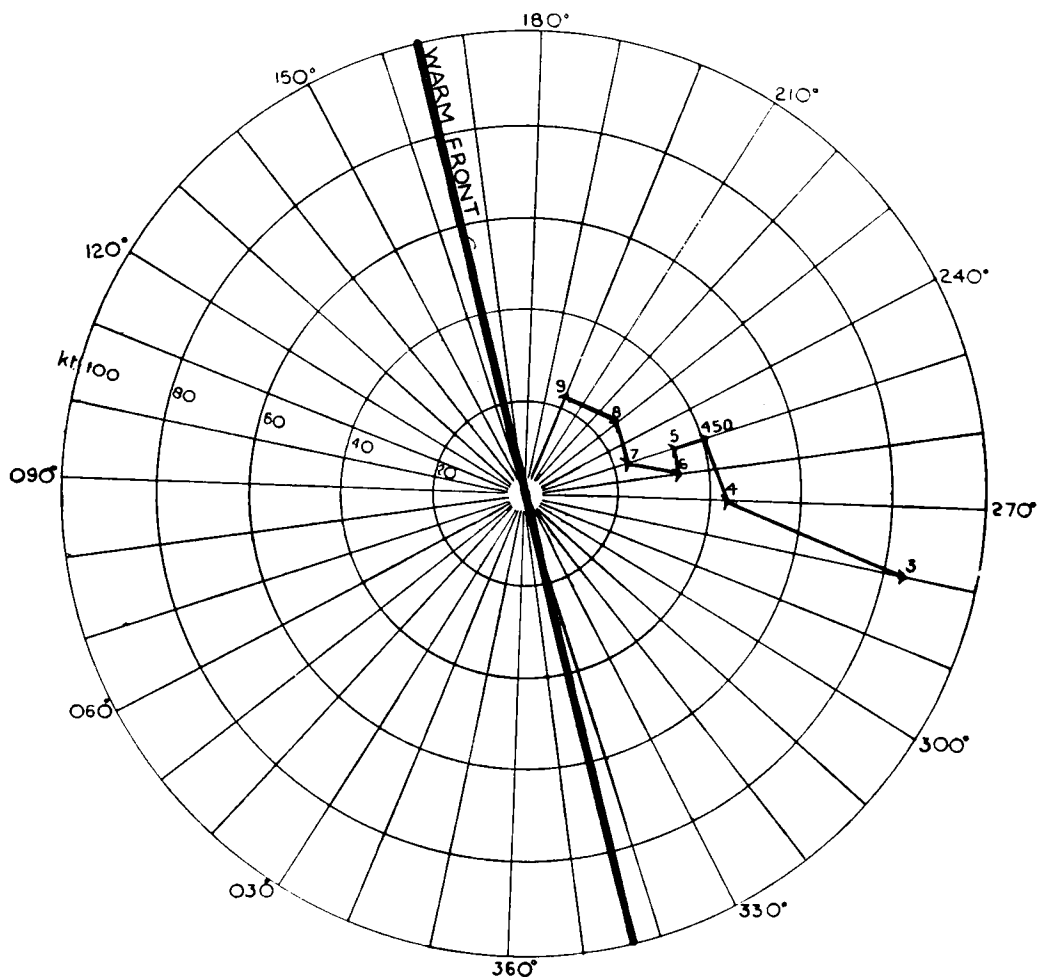


FIG. 6—HODOGRAPH OF WIND OVER LARKHILL,
0500, NOVEMBER 23, 1946

of the cold air over Larkhill at between 700 and 600 mb. The normal wind was increasing markedly with height above 700 mb. so we should have expected considerable rain from the front. This result was confirmed, as the front gave considerable rain in the south of England.

Fig. 7—1100 G.M.T., November 23, 1946.—At 1200 the cold front associated with the warm front discussed in the previous example was lying from $53\frac{1}{2}^{\circ}\text{N.}8\frac{1}{2}^{\circ}\text{W.}$ to $50\frac{1}{2}^{\circ}\text{N.}10^{\circ}\text{W.}$ to $47^{\circ}\text{N.}14^{\circ}\text{W.}$, i.e. just east of Valentia. The hodograph of the Valentia winds shows a normal wind increasing with height at practically all levels from 900 mb. to 400 mb. except in a shallow layer from 700 to 600 mb. This increasing normal wind indicates subsidence of the warm air down the cold-front surface and we should, consequently, expect the air to be dry, especially above 600 mb. This dryness of the air was confirmed by the reported humidities which were very low indeed above the 600-mb. level. This being so, the rain from the preceding warm front would be expected to die out in the area downwind from Valentia. This deduction was justified, as the rain in the Irish sea and the north of England, ahead of the preceding warm front and occlusion, soon ceased. At this stage a forecaster might have been tempted to forecast that the rain would die out all along the warm front.

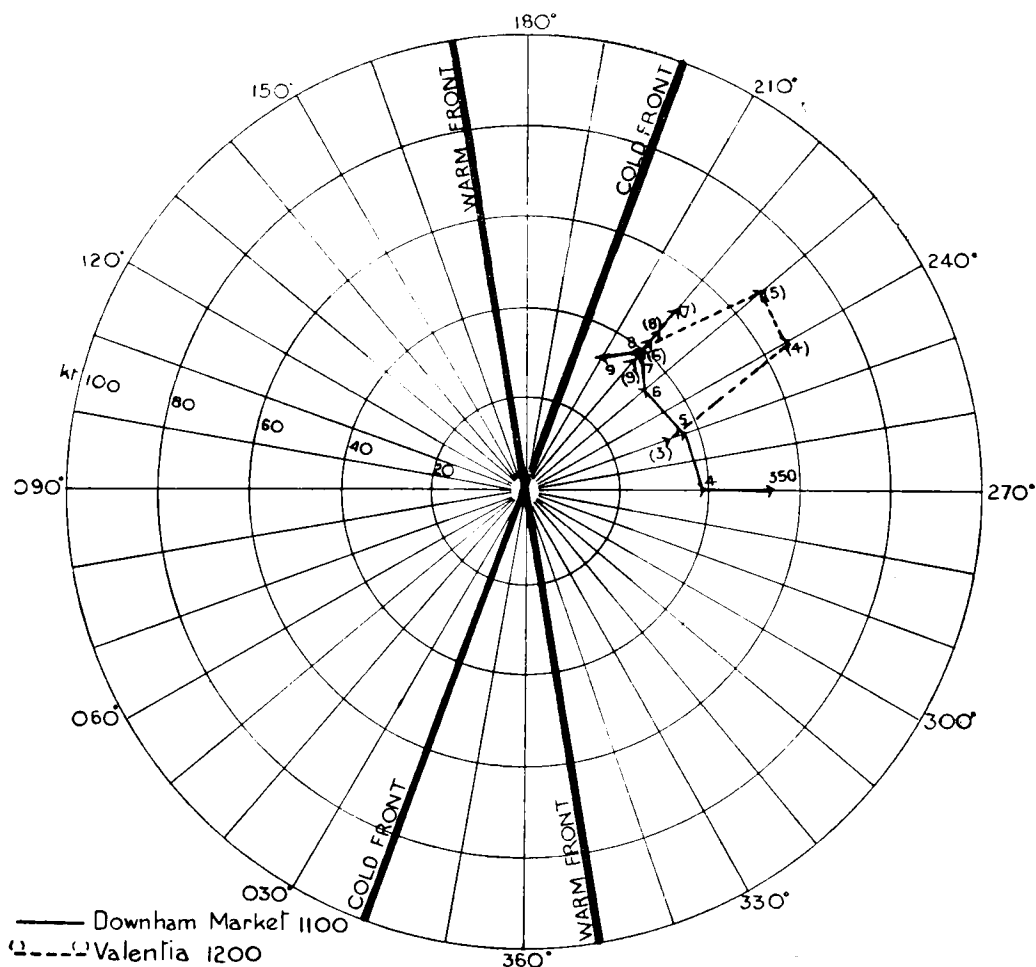


FIG. 7—HODOGRAPH OF WIND OVER DOWNHAM MARKET AND VALENTIA, NOVEMBER 23, 1946

However, this would have been incorrect as the warm front continued to give considerable rain in the south of England for some time, which shows that the warm air well to the south of Valentia had not subsided down the cold-front surface.

This example was discussed to illustrate the sudden development of subsiding motion down the cold front surface between 0500 and 1200 and illustrates a useful rule; if a warm front is active, *i.e.* the normal wind increases markedly with height, it will be followed by an inactive cold front. This rule holds the closer one approaches the tip of the warm sector. It clearly no longer holds at points along the cold front well away from the tip of the warm sector where the cold front is inclined at a small angle to the warm-sector isobars.

Wind discontinuity at the front and vertical velocity from the hodograph.—The hodograph can be used to obtain the wind discontinuity at a frontal surface, and then the vertical velocity of the warm air follows at once if the frontal slope is known.

Using the data contained in Fig. 1, Hodograph of wind over Larkhill on August 8, 1946, let us plot the normal wind in knots against the height in thousands of feet as in Fig. 8. It will be seen that the values of the normal wind

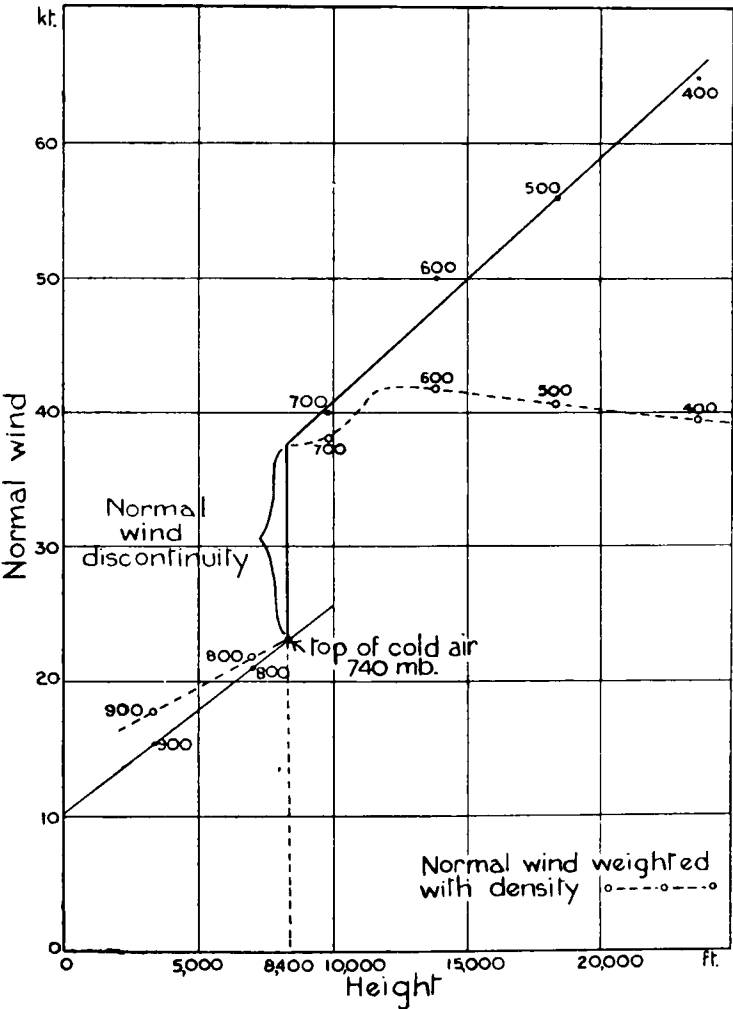


FIG. 8—RELATION BETWEEN NORMAL WIND AND HEIGHT

for the region 700 to 400 mb. lie on a straight line. If we produce this line back to the height corresponding to the top of the cold air, *i.e.* 8,400 ft. (740 mb.), we obtain the normal wind at this height in the warm air. The top of the cold air was obtained from the hodograph, Fig. 1, and is the height corresponding to a normal wind of 23 kt. The two values of the normal wind are thus:—

		kt.
Normal wind in the warm air (at 740 mb.)	..	$37\frac{1}{2}$
Normal wind in the cold air (at 740 mb.)	..	23
Wind discontinuity		15 approximately.

This shows that the warm air has a vertical velocity of $w = 15 \tan A$, where A is the angle of slope of the front. If two upper air ascents are available at different distances from the front then its slope can be obtained fairly accurately and the vertical velocity of the warm air computed.

Let us now weight the normal wind given in Fig. 8 with density, using the weighting formula;

$$\text{Weighted normal wind (at } p \text{ mb.)} = \frac{\text{Normal wind} \times \text{density (at } p \text{ mb.)}}{\text{density at 740 mb.}}$$

The results of these calculations are shown on Fig. 8 by the broken line. It will be seen that the weighted normal wind is practically constant with height. This suggests that the flow of the warm air in this case was practically two-dimensional and that the stream-lines were lines parallel to the frontal surface.

Rainfall estimates from hodograph analysis.—If u is the normal wind in the warm air at some level and u_f the speed of the front, then w , the vertical velocity of the warm air at the level where the normal wind is u , is given by

$$w = (u - u_f) \tan A.$$

If A is not known exactly $\tan A$ may be taken as $1/120$.

It follows that, by making assumptions as to the thickness of air taking part in rain production and its moisture content and using the vertical velocities obtained from the above formula, the rate of rainfall at a front can be calculated. However, it is found that with an active front the calculated rainfall is only a comparatively small fraction of the actual rainfall. The discrepancy undoubtedly arises from the following considerations: (1) the frontal lifting is much less than the actual lifting due to the realization of convective instability in the warm air, and (2) the effect of the presence of ice crystals in the upper parts of the cloud falling through the water drops lower down could greatly increase the rainfall above the calculated value.

The vertical velocity in the warm air at 8,400 ft. on August 8, 1946 was, assuming a frontal slope of $1/120$,

$$15/120 = \frac{1}{8} \text{ kt.} = 12\frac{1}{2} \text{ ft./min.}$$

and the vertical velocity at other heights would be inversely proportional to the density at the height considered. It would take the air about 6 hr. to be lifted vertically 5,000 ft. at approximately 13–14 ft./min. and the rate of rainfall would not exceed 2 mm./hr., which is a very low value.

It will be realised, therefore, that a quantitative estimate of the rainfall which will occur at a given place due to a given front can only be made from previous experience of similar situations in which such variables as frontal lift,

moisture content, humidity and instability have been correlated with actual rainfall. The hodograph will be used to decide when lifting is occurring and whether convective instability will be realised by the lifting; but cannot, unfortunately be used in calculating the rainfall directly.

Conclusion.—The foregoing examples should have been sufficient to give readers a good idea of the scope, use and value of the method of analysing upper wind structure near frontal surfaces by means of the hodograph. Many other interesting examples of the method could have been given had space permitted.

The hodograph can be used with advantage in other than frontal situations, but then no deductions as to vertical motion can be made.

Care should be taken when dealing with occlusions as the normal wind in the warm air above an occlusion does not exhibit anything like the marked increase with height shown by active warm fronts, but this does not mean that they will give no rain.

DETERMINATION OF THE TRUE MEAN VAPOUR PRESSURE OF THE ATMOSPHERE FROM TEMPERATURE AND HYGROMETRIC DATA

By E. J. SUMNER, B.A., and G. A. TUNNELL, B.Sc.

Part I

In practically any standard text-book of climatology the reader will find mean maps of barometric pressure, dry-bulb temperature, rainfall and so on; but maps of the mean moisture content of the atmosphere are rare, and really accurate maps, at least on a global scale, are non-existent. The Climatology Division of the Meteorological Office under the direction of Dr. C. E. P. Brooks, set out to remedy this deficiency. It was proposed to produce mean water-vapour-pressure maps, at screen height reduced to mean sea level, for the entire world for each season of the year, using all the climatic data available. The work is not yet complete, but it seemed opportune to give an account of how one particular difficulty was tackled. A fuller and more rigorous treatment is to be published elsewhere. Now vapour pressure is a non-linear function of the dry-bulb temperature and the relative humidity. Given the two latter values the corresponding vapour pressure may be computed from a formula or tables, but the mean vapour pressure cannot be determined from mean temperature and humidity using the same formula. A numerical example will illustrate the point: Helwan, Egypt, has a monthly mean temperature and relative humidity of $30\cdot8^{\circ}\text{A.}$ and 47 per cent. respectively, for July 1906–20. The vapour pressure computed from these values using standard tables^{1*} is 17·5 mb., whereas the true mean (*i.e.* the mean of individual values) is 16·1 mb., 1·4 mb. less.

Most climatological stations throughout the world publish only averages of temperature and relative humidity, sometimes with the range of one or both. Others give wet- and dry-bulb temperatures, or dry-bulb and dew-point temperatures. The vapour pressure value derived from these published means is, as we have seen, liable to depart considerably from the true mean because

*These numbers refer to the list of references on p. 263.

of the "error of the means" as it may be called, and the following account deals with the various methods of determining the true mean vapour pressure. It is shown how the errors arise in each case and what their magnitude is likely to be in various climatic regions. Some indications as to how to compute these errors in certain cases quickly from existing data are also given, although on occasions the question is not so much one of speed, as of getting the required mean vapour pressure at all.

Calculation of mean vapour pressures from dry-bulb temperature and relative humidity data.—If T is the dry-bulb temperature, a the corresponding saturation vapour pressure (written $a(T)$ where its explicit dependence on temperature requires to be brought out), and b the relative humidity expressed as a decimal fraction, then e , the vapour pressure of the atmosphere, is equal to ab . The true mean vapour pressure, $\bar{e}$, for n observations, is given by

$$\begin{aligned}\bar{e} &= \frac{1}{n} \sum e = \frac{1}{n} \sum ab = \overline{ab} \\ &= \overline{a\bar{b}} + \frac{1}{n} \sum (a - \bar{a}) (\bar{b} - b) \\ &= \overline{a\bar{b}} + r\sigma_a\sigma_b, \quad \dots \dots (1)\end{aligned}$$

where r is the coefficient of correlation between a and b , σ_a the standard deviation of the a 's, and σ_b that of the b 's.* Let the value of the vapour pressure determined directly from the mean temperature $\bar{T}$, and mean humidity, $\bar{b}$ be E , then $E = a(\bar{T})\bar{b}$, $a(\bar{T})$ being the value of the saturation vapour pressure corresponding to the mean temperature. The amount, S , to be added to this value in order to give the true mean is given by

$$S = \bar{e} - E = \{\overline{a(T)} - a(\bar{T})\}\bar{b} + r\sigma_a\sigma_b \quad \dots \dots (2)$$

There are therefore two distinct sources of error: the first, S_1 , owing to the non-linearity of the relation between temperature and saturation vapour pressure; and the second, S_2 , owing to the correlation between saturation vapour pressure and relative humidity, which arises from the obvious fact that the equation $e = ab$ is non-linear in a and b . To calculate the correction S , $\bar{a}$, σ_a , and r must be expressed in terms of temperature and humidity data ($\bar{a}$ and σ_a are expressible in terms of temperature only). We shall deal with each item in turn.

If the units of temperature and vapour pressure are degrees absolute and millibars respectively, then

$$\log \left\{ \frac{a(T)}{a(T_0)} \right\} = \alpha \left(\frac{1}{T_0} - \frac{1}{T} \right) \quad \dots \dots (3)$$

where T_0 is some convenient "zero" temperature, and α is a constant differing for ice and water². The theoretical values of α for saturation with respect to water or supercooled water and ice are 5,423 and 6,140 respectively. In practice, a value of α of 5,305 for water has been found to give better agreement with accepted values of $a(T)$. It was arrived at by assuming a relationship of the form $\log a(T) + \alpha/T = \beta$, as suggested by theory, and finding by least squares the most probable values of the constants α and β over the temperature range 260–310°A., using values of the saturation vapour pressure at one-degree intervals as given by the British hygrometric tables¹

*A bar placed over a symbol denotes the mean value.

up to 304°A., and thereafter from the Smithsonian tables.³ The exact result was $\log a(T) + 5304.87/T = 21.255$. This equation may be put in the form of equation (3), where $a(T_0)$ and T_0 now represent any point on the best-fitting curve, in which case $a(T_0)$ is not necessarily the actual value of the saturation vapour pressure at the temperature T_0 . The difference is inappreciable, however, and equation (3), with $\alpha = 5.305$, has been found to be extremely accurate with any pair of initial values which actually occur, and we have adopted it in the subsequent analysis.

If T' is the departure of a particular temperature from the average of the n observations of which it forms part, *i.e.* $T = \bar{T} + T'$, we may expand $a(T)$ by Taylor's theorem in the form

$$a(T) = a(\bar{T}) + \frac{T'}{1!} \left(\frac{da}{dT} \right)_{\bar{T}} + \frac{T'^2}{2!} \left(\frac{d^2a}{dT^2} \right)_{\bar{T}} + R_3,$$

where R_3 is the remainder after three terms. There are n equations of this form corresponding to each temperature reading; summing and dividing by n we get

$$\bar{a}(T) = \frac{1}{n} \sum a(T) = a(\bar{T}) + \left(\frac{d^2a}{dT^2} \right)_{\bar{T}} \left(\frac{1}{2n} \sum T'^2 \right) + \frac{1}{n} \sum R_3,$$

since $\sum T' = 0$. Now from equation (3)

$$\frac{d^2a}{dT^2} = \frac{a(T)}{T^4} (\alpha^2 - 2\alpha T)$$

Therefore
$$\bar{a}(T) = a(\bar{T}) + \frac{a(\bar{T})\sigma_T^2}{\bar{T}^4} (\alpha^2 - 2\alpha\bar{T}) + R,$$

in which R is the mean remainder and σ_T is the standard deviation of the temperature data. Although a rigorous proof cannot be given here, it can be shown that R is normally negligible by comparison with the other terms, and our final equation expressing $\bar{a}(T)$ in terms of the temperature data only is

$$\bar{a}(T) = a(\bar{T}) \left\{ 1 + \frac{\sigma_T^2}{2\bar{T}^4} (\alpha^2 - 2\alpha\bar{T}) \right\} \dots \dots (4)$$

The following is a typical example illustrating the accuracy of this equation. The monthly mean temperature of Basra for July 1938-41 is 306.89°A., and $\sigma_T = 3.71^\circ\text{C.}$, $a(\bar{T}) = 52.84$ mb. (from tables), and $\bar{a}(T) = 53.84$ mb.* The actual difference between these two values is 1.01 mb. whereas $\bar{a}(T) - a(\bar{T})$ calculated from the above equation, is 1.00 mb. For temperatures which occur in nature $\bar{a}(T)$ is always greater than $a(\bar{T})$.

To determine σ_a we merely put $a = \bar{a} + a'$ and $T = \bar{T} + T'$ in (3), expand, take averages of both sides and neglect powers higher than the second. We shall leave the algebra to the reader; the result is

$$\frac{\sigma_a}{a} = \frac{\alpha\sigma_T}{\bar{T}^2}$$

However, the equation finally adopted was

$$\frac{\sigma_a}{a(\bar{T})} = \frac{\alpha\sigma_T}{\bar{T}^2} \dots \dots (5)$$

It expresses σ_a in terms of the mean temperature and the standard deviation of the temperature only, and is rather more accurate than the first. It can be

*The standard deviation is calculated from the monthly mean temperatures at each of the 24 hours of the day, and $\bar{a}(T)$ is the mean of the saturation vapour pressures at these temperatures.

taken as applying to all diurnal ranges of temperature, and to all hourly and annual ranges less than 20°C., to well within 5 per cent. of the actual standard deviation of saturation vapour pressure.

Substituting from (4) and (5) in (2), we get

$$S=\left\{\frac{a(T)\sigma_T^2}{2\overline{T}^4}\left(\alpha^2-2\alpha\overline{T}\right)\right\}\overline{b}+ra(\overline{T})\frac{\alpha\sigma_T\sigma_b}{\overline{T}^2}\dots\dots(6)$$

This equation gives a remarkably accurate value for the required correction, and except for the correlation coefficient *r*, refers only to the original temperature and humidity data. Before proceeding further it would be as well to give some typical values of the entities which occur in it. Tables I, II and III represent a small selection of a large number of stations for which the calculations were made. It will be seen at a glance that the total error *S* is negligibly small for monthly means at a particular hour, and it can be taken for granted that if the mean temperature and mean relative humidity are used to compute the vapour pressure we shall generally be within 0.2 mb. of the true mean, especially in the tropics. Such corrections are not significant, and reference will be made to means of this type again in Part II.

The other types of means most frequently used will be discussed separately.

Monthly means.—The values of *r*, *σ_a*, *σ_b* in Table II were derived from the 24 monthly mean values of temperature and relative humidity at each of the 24 hours (or as many as were available down to a minimum of eight). The

TABLE I—MONTHLY MEANS AT SPECIFIED HOURS

Place	Date	Time	$\overline{T}$	$\frac{\overline{b}\times}{100}$	<i>r</i>	<i>σ_a</i>	$\frac{\sigma_b\times}{100}$	<i>σ_T</i>	<i>S</i> ₁	<i>S</i> ₂	<i>S</i>
		G.M.T.	°A.	%		mb.	%	°C.	mb.	mb.	mb.
Aboukir	Jan. 1946	0600	286.8	75	−0.74	2.1	11.8	2.1	0.10	−0.18	−0.08
		1200	290.0	60	0.00	0.9	5.7	0.7	0.01	0.00	+0.01
	July 1946	0600	299.0	75	−0.04	1.1	5.9	0.5	0.01	0.00	+0.01
		1200	300.9	67	−0.15	1.8	6.6	0.8	0.03	−0.02	+0.01
New York	Jan. 1941	0600*	270.3	71	+0.47	1.8	13.7	4.5	0.17	+0.11	+0.28
		1200*	273.2	65	−0.04	1.7	14.6	3.6	0.12	−0.01	+0.11
	July 1941	0600*	293.9	78	+0.05	3.9	10.0	2.5	0.22	+0.02	+0.24
		1200*	299.7	62	−0.47	8.2	17.9	3.9	0.50	0.70	+0.20
Kew	Jan. 1935	0600	277.6	87	0.00	2.1	9.6	3.4	0.19	0.00	+0.19
		1200	279.0	80	−0.07	2.0	9.7	3.1	0.14	−0.01	+0.13
	July 1935	0600	278.6	81	+0.09	2.0	7.3	1.8	0.11	+0.01	+0.12
		1200	294.7	54	−0.21	4.4	8.8	2.6	0.30	−0.08	+0.22

* 75° West Meridian Time

TABLE II—MONTHLY MEAN VALUES

Place	Month	Period	$\overline{T}$	$\frac{\overline{b}\times}{100}$	<i>r</i>	<i>σ_a</i>	$\frac{\sigma_b\times}{100}$	<i>σ_T</i>	<i>S</i> ₁	<i>S</i> ₂	<i>S</i>
			°A.	%		mb.	%	°C.	mb.	mb.	mb.
Helwan	Jan.	1906–20	286.0	58	−0.99	2.8	9.9	2.7	0.13	−0.25	−0.12
	July	1906–20	300.8	47	−0.98	10.1	19.4	4.5	0.54	−1.92	−1.38
Alexandria	Jan.	1906–20	287.7	69	−0.99	2.0	6.0	1.8	0.07	−0.12	−0.05
	July	1906–20	298.6	75	−0.97	4.2	5.8	2.1	0.18	−0.23	−0.05
Kew	Jan.	1935	278.2	84	−0.98	0.4	3.9	0.7	0.01	−0.02	−0.01
	July	1935	292.0	66	−0.99	4.1	12.5	2.9	0.22	−0.51	−0.29

correction S in this case is the departure of the vapour pressure, computed from the mean temperature and humidity, from the average of the hourly values computed in the same way from the monthly mean temperature and humidity at the hours, each of which is as already shown very close to the true value. Thus, adding S to the computed vapour pressure should give the true mean to within 0.2 or 0.3 mb. on an average.

It is obvious from the table that we are dealing with much bigger errors than have previously arisen, and it is possible to give a much more systematic account of them. The correlation coefficient r is now always negative and as near unity as to make no difference, and therefore our fundamental equation becomes

$$\Delta S = \left\{ \frac{a(\bar{T})\sigma_T^2}{2\bar{T}^4} (\alpha^2 - 2\alpha\bar{T}) \right\} \bar{b} - \left\{ \frac{a(\bar{T})\alpha\sigma_T}{\bar{T}^2} \right\} \sigma_b \quad \dots (7)$$

The two terms which make up the correction are always of opposite sign in this case, which helps to diminish the error, but the negative one invariably overrides the other, except possibly when the value of S is very small indeed. In an unpublished paper we have also found a relationship between σ_T , σ_b , and $\bar{b}$, which simplifies the equation further. It is

$$\frac{\sigma_b}{\bar{b}} = \alpha_1 \frac{\sigma_T}{\bar{T}^2} \quad \dots (8)$$

where α_1 is a constant which is equal to α when there is no diurnal variation of vapour pressure at the place in question, and which is greater or less than α according to whether the vapour-pressure profile has a minimum during the day-time or not; the bigger the amplitude of the variation the bigger the effect. With the aid of this equation we have shown that S is roughly proportional to the square of the temperature range, the constant of proportionality increasing both with the mean temperature and the range of relative humidity. For mean diurnal temperature ranges less than 10°C., which include those of most temperate regions and all coastal stations with an on-shore wind, even in the tropics, the correction is usually much less than 0.5 mb.; but, above this range, it increases very rapidly, depending on the range of relative humidity. The greatest errors are experienced in arid regions in the tropics, well removed from the coast, where they may reach 2 mb. or more.

Annual means.—The various values of r , σ_a , σ_b , etc., in Table III were calculated from the twelve monthly mean temperatures and relative humidities. The quantity S is the departure of the mean vapour pressure, computed from the annual means of temperature and humidity, from the average of the computed monthly means, each of which is generally greater than the true monthly mean of vapour pressure. In temperate and polar regions, where the biggest annual ranges are experienced, this usually amounts to 0.3–0.4 mb. at the most, and the value of S gives a good idea of the magnitude of the error of

TABLE III—ANNUAL MEAN VALUES

Place	Period	$\bar{T}$	$\frac{b \times}{100}$	r	σ_a	$\frac{\sigma_b \times}{100}$	σ_T	S_1	S_2	S
		°A.	%		mb	%	°C.	mb.	mb.	mb.
Helwan	1906–20	294.2	50	–0.47	8.0	6.8	5.2	0.58	–0.25	+0.33
New York	1941	285.6	62	+0.07	8.9	3.9	9.1	1.38	+0.03	+1.41
Kew	1935	283.7	77	–0.73	4.5	6.3	4.9	0.46	–0.21	+0.25
Blagovyeshchensk	7 yr.	273.3	77	+0.13	8.8	5.9	15.9	2.94	+0.07	+3.01

the means. For annual means at a particular hour the order of magnitude of the error is about the same as that given in the table, and S represents the true correction more accurately.

The correlation coefficient r is here very variable, and no general rules can be given about it. The correction always seems to be positive, partly because the correlation is smaller than with monthly means, but mainly because the annual ranges of temperature are, in proportion, larger than those for humidity. Generally speaking the amount of moisture in the air depends on its capacity to receive it, and a seasonal rise of temperature is invariably associated with a rise of moisture content and a correspondingly small range of relative humidity.

Mean vapour pressures may be in error by over 3 mb. in high latitudes if computed from annual means of temperature and humidity, but are usually more or less correct in the tropics. This computed value is always less than the true mean vapour pressure and is very approximately proportional to the square of the temperature range. It is usually best to work out the monthly means with their appropriate corrections and average them to get the annual mean.

(*To be continued*)

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SOME CORRELATIONS CONCERNING THE THICKNESS OF THE 500-300-MB. LAYER

BY R. MURRAY, M.A.

Introduction.—Correlation coefficients and regression equations connecting the thickness of the 500-300-mb. layer with (1) temperature on the 500-mb. surface, (2) thickness of the layer 700-500 mb., and (3) temperature on the 300-mb. surface are given in this note. In addition some remarks are made regarding the occurrence of the tropopause below 300 mb.

A good deal of the substance of this note is already empirical knowledge to upper air analysts, but it is desirable that it should be put on paper in as definite a form as possible.

The data used consisted of 943 temperature soundings at Larkhill and Lerwick for the months of January, April, July and October 1947. A great variety of weather was represented by these soundings. The conclusions reached from the analysis may therefore be considered applicable to the British Isles generally, and probably, in only slightly modified form, to much of the eastern Atlantic and Europe between latitudes 45°N. and 65°N.

Correlation of the thickness of the 500-300-mb. layer with temperature at 500 mb.—S. Petterssen* found a correlation coefficient of about .97 between the 500-400-mb. thickness and the temperature on the 500-mb.

* PETTERSSSEN, S.; Relation between the temperature in the 500-mb. surface and the thickness of the layer from 500 to 400 mb. *S.D.T.M. met. Off.*, London, No. 88, 1944.

surface. In our case practically the same correlation results—actually, $\cdot968 \pm \cdot001$.

The regression equation giving the most probable value of t_3 when T_5 is known is:—

$$t_3 = 23\cdot47 T_5 + 1,884$$

where t_3 = thickness of the 500–300-mb. layer in feet, and T_5 = temperature at 500 mb. in degrees Fahrenheit.

The standard error of t_3 for given T_5 is 66 ft. In other words the value of t_3 obtained from the regression equation will be different from the true value of t_3 by less than about 130 ft. on rather more than 95 per cent. of occasions. Table I is derived from the regression equation.

TABLE I—500–300-MB. THICKNESS CORRESPONDING TO TEMPERATURE AT 500 MB.

T_5 (°F.)	–35	–30	–25	–20	–15	–10	–5	0	5	10	15	20
t_3 (ft.)	11,063	11,180	11,297	11,415	11,532	11,649	11,766	11,884	12,001	12,119	12,236	12,353

Correlation of the thickness of the 500–300-mb. layer with the thickness of the 700–500-mb. layer.—The correlation coefficient between t_3 and t_5 is equal to $\cdot944 \pm \cdot002$ (t_5 = thickness of 700–500-mb. layer in feet), and the required regression equation is:—

$$t_3 = 1\cdot306 t_5 + 751$$

Here the standard error of t_3 for given t_5 is 87 ft. and Table II is derived from the regression equation.

TABLE II—500–300-MB. THICKNESS CORRESPONDING TO 700–500-MB. THICKNESS

t_5 (ft.)	8,000	8,100	8,200	8,300	8,400	8,500	8,600	8,700	8,800	8,900
t_3 (ft.)	11,199	11,330	11,460	11,590	11,721	11,852	11,983	12,113	12,244	12,374

General remarks.—It appears that slightly better estimates of t_3 can be made by using T_5 than by using t_5 . However, in practical upper air work it will often be more convenient to make estimates based on knowing t_5 . A total correlation coefficient and regression equation connecting t_3 with T_5 and t_5 could be worked out, but the resulting probable values of t_3 could be only slightly more accurate than estimates made from T_5 alone.

Correlation of the thickness of the 500–300-mb. layer with temperature at 300 mb.—As the tropopause is occasionally located at a lower level than the 300-mb. surface, it was thought desirable to work out correlation coefficients and regression equations in the following three cases:—

(a) *All occasions (i.e. position of tropopause not specified).*—Let T_3 be the temperature at 300 mb. in degrees Fahrenheit. Then correlation between t_3 and T_3 is $\cdot867 \pm \cdot005$.

The regression equation giving the most probable value of T_3 when t_3 is known is:—

$$T_3 = \cdot0268 t_3 - 365$$

The standard error of T_3 for given t_3 is $4\cdot2^\circ\text{F}$.

(b) *Tropopause at or above 300 mb.*—There were 866 occasions. The correlation coefficient is $\cdot911 \pm \cdot004$ and the regression equation is:—

$$T_3 = \cdot02915 t_3 - 393$$

The standard error of T_3 for given t_3 is $3\cdot5^\circ\text{F}$.

J. M. Craddock* found a correlation coefficient of .96 between the temperature at 500 mb. and the 700–500-mb. thickness. At first sight it may be rather surprising that in our case the correlation coefficient between t_3 and T_3 is only .911 and not about .95 in the upper troposphere. There is little doubt that the correlation coefficient would be somewhat greater than .911 if those cases, in which the temperature lapse rate near 300 mb. changed appreciably yet without quite qualifying to be classed as a tropopause, had been excluded from the statistics.

(c) *Case of tropopause below 300 mb.*—There were 77 occasions. The correlation coefficient is $.70 \pm .04$, and the regression equation is:—

$$T_3 = .02715 t_3 - 362$$

The standard error of T_3 for given t_3 is 4.8°F .

Table III gives the probable values of T_3 for certain values of t_3 for all three cases. In case (c) it applies fairly well within the range $11,200 \leq t_3 \leq 11,700$.

TABLE III—TEMPERATURE AT 300 MB. CORRESPONDING TO 500–300-MB. THICKNESS

500–300-mb. thickness	Temperature at 300 mb.		
	(a) All occasions	(b) Tropopause at or above 300 mb.	(c) Tropopause below 300 mb.
ft.	<i>degrees Fahrenheit</i>		
12,400	–33	–32	—
12,300	–35	–34	—
12,200	–38	–37	—
12,100	–41	–40	—
12,000	–43	–43	—
11,900	–46	–46	—
11,800	–49	–49	—
11,700	–51	–52	–44
11,600	–54	–55	–47
11,500	–57	–58	–50
11,400	–59	–61	–52
11,300	–62	–64	–55
11,200	–65	–67	–58

General remarks.—The regression equations and Table III should prove helpful in forecasting temperatures at 300 mb. when forecasts are made of the 500–300-mb. thickness (as is the present British practice). If the position of the tropopause is likely to be very doubtful, the regression equation or column (a) in Table III will give a first approximation to the temperature at 300 mb. If the tropopause is expected to be above 300 mb., the information in column (b) should be used, and if the tropopause is probably below the 300-mb. level, use should be made of the results in column (c). In each case synoptic experience will modify the forecast based on the statistical method.

Occurrence of the tropopause below 300 mb.—About 8 per cent. of all the soundings showed the tropopause below the 300-mb. level. When t_5 was equal to, or greater than, 8,500 ft., the tropopause was invariably higher than the 300-mb. level. Table IV gives the percentage frequency of occurrence of the tropopause below 300 mb. for various values of t_5 .

*CRADDOCK, J. M.; Estimation of temperature in the 700-mb. and 500-mb. surfaces. *Met. Mag.*, London, 78, 1949, p. 36.

TABLE IV—FREQUENCY OF TROPOPAUSE BELOW 300 MB. FOR VARIOUS VALUES OF
700–500-MB. THICKNESS

t_5 (ft.)	8,500	8,450	8,400	8,350	8,300	8,250	8,200	8,150	8,100	8,050	8,000–7,800
Frequency (%)	0	3	11	18	3	7	19	20	33	32	35

It will be seen that, on the whole, the smaller the value of t_5 (the colder the air) the greater the chance of the tropopause being below 300 mb. However, the most useful working rule which comes out from the statistics is that it is nearly a certainty that the tropopause will be at a greater height than the 300-mb. surface in cases when t_5 is greater than 8,450 ft. (8,400 ft. is a standard thickness line on the 500-mb. chart).

METEOROLOGICAL RESEARCH COMMITTEE

The seventh meeting of the Physical Sub-Committee was held on July 20, 1949.

Members heard with interest that observations of temperature and wind to a height of about 100,000 ft. had recently been made on five occasions, using special balloons to carry the radio-sonde.

The Sub-Committee discussed a paper¹ describing recent experiments at Kew Observatory on heat transfer near the ground by N. E. Rider and Dr. G. D. Robinson.

A report² from Mr. R. F. Jones on the relation between the radar echoes from cumulus and cumulonimbus clouds and the turbulence within these clouds was received with interest.

Papers on condensation processes in clear air at low temperatures and self propagation of ice crystals in supercooled water clouds were considered and future work on low temperature investigations decided.

Other papers considered were on the size distribution of raindrops³ and the detection of icing conditions by radar⁴, both by Mr. R. F. Jones; condensation trails made by jet aircraft were also discussed.

¹*Met. Res. Pap., London*, No. 491

²*Met. Res. Pap., London*, No. 484

³*Met. Res. Pap., London*, No. 453

⁴*Met. Res. Pap., London*, No. 482

ROYAL METEOROLOGICAL SOCIETY

At a meeting of the Royal Meteorological Society on Wednesday, June 15, 1949, Sir Robert Watson-Watt, President, in the Chair, the following papers were read:—

*Hewson, E. W.—The dissipation of scattered and broken cloud.**

In the absence of the Canadian author this paper was read by Prof. Brunt, who said that the paper had had its origin in a lecture he had given in 1936.

It had been shown in 1944 that the rate of net loss of heat by a cloud due to radiation was $\gamma\sigma(T_T^4 - T_S^4 + T_B^4)$ where $\gamma = 0.35$, σ = Stefan's constant, and T_T , T_B and T_S were the absolute temperatures at the top and base of the cloud and surface of the earth, respectively. With this value (or more accurately using Elsasser's radiation chart) it was possible to deduce the behaviour of the cloud under radiation conditions from the tephigram. As the cloud cooled, its

Quart. J. R. met. Soc., London*, **74, 1948, p. 243.

temperature followed an isobaric curve on the tephigram, and then, being colder than its environment, a saturated adiabatic until it was at the same temperature as its environment. In this way a cooling cloud would descend and, in fact, become warmer and progressively drier as it descended. The process, as illustrated in slides and on the blackboard, was in steps but these could be as small as desired and, in the limit, the cooling would take place along the environment curve.

The total amount of the different states of water in the cloud could be represented by a single value of the symbol ξ where $\xi = x+y+z$, x , y and z being the numbers of grams of water vapour, liquid water and ice, respectively, per kilogram of dry air; and this could be represented on the tephigram for all pressures, by the saturated mixing-ratio line of the same value.

When the cloud had "cooled" sufficiently so that its temperature reached this ξ line, any further cooling would result in evaporation and the cloud would dissipate.

Several slides were shown illustrating the process for various different lapse rates of the environment curve and how it was theoretically possible for the cloud to descend even as far as the ground. The radiation did take time, however, and a period of 6 hr. was quite normal.

Speaking for himself, Prof. Brunt doubted whether radiation was the only effect; not only did the cloud descend, but, in descending, the air beneath the cloud would probably also descend, and since this air would warm at the dry adiabatic lapse rate a temperature difference would arise sufficient to set up convection. Once, at Nottingham, he had been able to describe a sheet of cloud as 8 tenths and as dissipating within half an hour. He had seen rolls and breaks near the edge of the sheet and had suspected turbulence; the amount of cloud had fallen to 3 tenths within 15 min.

The technique of the ξ line was useful in giving a criterion of the descent required before a cloud dissipates; but it was necessary to remember that a cloud can fall through the air.

Mr. A. W. Brewer had had to forecast in north-east England during the war and try to determine what would happen to a given sheet of cloud. He drew diagrams of the history of 10 tenths sheets of thin cloud which either descended and became thicker or dissipated, even though, initially, the environments were similar. The final result seemed to depend on the amount of turbulence present.

Mr. D. J. Schove had observed warm-sector stratus break into rolls and disappear.

Dr. R. C. Sutcliffe wondered if the step-by-step process could be written as a differential equation which would perhaps be better understood. It was important to realise that instability for cloud-laden air was the same for both up and down motion. In conclusion, he thought the paper was a useful exercise in what could be done with the tephigram, and would be valuable for students.

Prof. Brunt, in reply, mentioned that he had not had the opportunity of studying the temperature structure in north-east England before. In his experience of lecturing he had found that his "simple-minded" students preferred step-by-step methods to differential equations.

*Crocker, A. M.—Synoptic applications of the frontal contour chart.**

In the absence of the author, also Canadian, this paper was read by Dr. J. S. Farquharson. A frontal-contour chart is prepared in two steps:—

(a) by analysing all available upper air data and finding levels of separation of the air masses present, and

(b) by drawing the lines of intersection of the frontal surfaces with the pressure surfaces of 900, 800, 700 . . . mb.

From these frontal-contour charts it was frequently possible to identify a cold air mass penetrating southwards in a long tongue; warmer air, moving in further north and progressively lower, might cut off the cold air completely leaving a cold dome behind. Mr. Crocker preferred the term “cold dome” to Mr. Douglas’s term “cold pool”† because his frontal-contour charts indicated that they were dome-shaped, unless they reached the tropopause when they were similar to the frustrum of a cone.

The paper was illustrated by a detailed analysis of a cold dome covering south-west United States including tephigrams, frontal-contour charts and isobaric-contour charts as well as the normal surface charts. The charts showed how the cold dome moving north-eastwards, as shown by a low on the 300-mb. charts, united with a surface low which was then moving north-westwards; the surface low deepened more rapidly when the uniting took place and both lows then moved almost together.

Among the advantages of frontal-contour charts was the ability to estimate from them probable vertical movements and condensation.

Dr. Farquharson, in opening the discussion, thought that there was no more justification for the term “cold dome” than for “cold pool”. “Cold pool” had been invented during telephone conferences in Bomber Command; the name had stuck and he was in favour of it for day-to-day purposes.

Mr. A. G. Matthewman had been investigating frontal structure. There were difficulties in the Norwegian concept of a front; some people preferred other definitions, *e.g.* a line of appropriate weather. Fronts might be rather vague in regions of frontolysis and frontogenesis. He had been experimenting with constant-pressure charts with isopleths of wet-bulb potential temperature which he thought took frontal-contour charts in their stride. He was doubtful of Mr. Crocker’s statement that the air round the surface centre was quasi-homogeneous, and he produced charts he had constructed to substantiate his belief that the deepening had been caused by a limited occlusion process, in the non-homogeneous polar maritime air.

Mr. H. H. Lamb had worked with both frontal-contour charts and thickness charts; and thickness charts were important in the appreciation of thermal steering. He thought that there were both cold pools and cold domes; domes were sometimes present in cold pools, but cold pools, which were defined as closed areas on the thickness chart, sometimes included patches within a single air mass. He described an interesting situation in March 1946 when there was both a cold dome and a cold pool.

Quart. J. R. met. Soc., London*, **75, 1949, p. 57.

†DOUGLAS, C. K. M.; Cold pools. *Met. Mag., London*, **76**, 1947, p. 225.



CUMULUS AND CUMOLONIMBUS IN THE RAINY SEASON ON THE COAST OF BRITISH EAST AFRICA
(see p. 270)



CUMULUS AND ALTOCUMULUS OVER CENTRAL TANGANYIKA
(see p. 270)

Dr. R. C. Sutcliffe saw no grounds for controversy in nomenclature; either term was appropriate according to circumstances. The cold "whatever it is" had received a lot of attention; it existed over continents in winter, associated with anticyclones, but persistent cold pools were more typical of cold depressions.

In reply, Dr. Farquharson said that frontal-contour charts were useful for special investigations, but not as a general tool of forecasting owing to the lack of sufficiently detailed information for their construction.

ROYAL ASTRONOMICAL SOCIETY

At a geophysical discussion of the Royal Astronomical Society on May 27, 1949, the following paper by Mr. C. S. Durst was read:—

On surface friction and turbulence in the ocean.

The purpose of the paper was to show how the roughness of the ocean surface due to wave formation affected the coefficient of surface friction and how this varied with wind speed. This variation also enabled a calculation to be made of the coefficient of turbulence in the ocean when it was under the influence of winds of varying strengths.

It is usually assumed that the surface resistance, F_x , is proportional to the density and the square of the wind speed, the equation being written:—

$$F_x = K\rho V_s^2 \quad \dots (1)$$

where ρ is density and V_s the "surface" wind. The value of K is often assumed to be 0.002 but Sutcliffe* found that over the ocean the value was much lower. Sutcliffe, in making this estimate, used the formula:—

$$F_x = \int_0^h 2 \omega \sin \phi \rho (v - v_g) dz \quad \dots (2)$$

where v is the wind component at right angles to the "surface" wind direction, v_g is the component of the geostrophic wind in the direction which is reached at height h , ω is the angular velocity of the earth and ϕ is latitude.

In the present paper this formula was used to estimate the surface resistance from two series of data, the first being pilot-balloon ascents made by D. A. Davies from S.S. *Manchester Port* and the second being observations made on H.M. Ships.

The conclusion reached from the examination was that the surface resistance over the sea varied as a higher power than the square of the "surface" wind, and it seemed that K in equation (1) was proportional to the surface wind speed.

To relate this result to the turbulence in the ocean a result deduced by Jeffreys† was invoked, namely:—

$$k = \frac{F_x}{2 \omega \sin \phi j^2} \quad \dots (3)$$

where k is the coefficient of turbulence in the ocean (assumed constant with depth) and j is the velocity of the ocean current. The link between this formula and (1) was provided by an empirical result obtained by Durst‡ that the speed of the ocean current was proportional to the surface wind.

*SUTCLIFFE, R. C.; Surface resistance in atmospheric flow. *Quart. J. R. met. Soc.*, London, **62**, 1936, p. 3.

†JEFFREYS, H.; On turbulence in the ocean. *Phil. Mag.*, London, **39**, 1920, p. 578.

‡DURST, C. S.; The relationship between current and wind. *Quart. J. R. met. Soc.*, London, **50**, 1924, p. 113.

Using this formula it was found that the coefficient of turbulence in the ocean was of the order of 10^{-2} for a light air, 30 for a moderate breeze of 15 kt. and 200 for a strong breeze of 25 kt.

In the discussion which followed, Prof. D. Brunt pointed out that the coefficient of skin friction depended on the height at which the "surface" wind was measured, and that with the sea observations this height had not been stated. To this Mr. Durst replied that the height of the "surface" wind observed at sea might be rather indefinite, but in the data used for the comparison of wind and current and for the determination of surface friction by pilot balloons the observations referred essentially to the same heights.

Prof. P. A. Sheppard asked if Mr. Durst had been able to find evidence of the change in the value of the drag coefficient at critical wind speeds as would be expected from the work of Munk. Mr. Durst replied that he had not—indeed the observations would be too few for such refinement. He felt that it would be well to endeavour to obtain more, and more accurate, observations perhaps from the Admiralty to settle the question if possible.

Dr. G. E. R. Deacon referred to Prof. Jeffrey's work on waves, and said that the explanation of the discrepancy between the magnitudes of the coefficient of turbulence deduced from the movement of ocean drift currents and that required in the formation of waves might be that the turbulence needed to create water movements was of a different type to that involved in the wave motion.

Mr. A. F. Crossley stated he had used Mr. Durst's data to calculate the value of the index on the assumption of a power law variation of wind with height. He exhibited a diagram which showed that the *Manchester Port* data (excepting light winds) fitted a power law. If, however, the coefficient of surface friction were calculated on the supposition that the power law variation held down to the surface it was found that the coefficient was nearer to that used by Prof. Taylor over the land than that deduced by Dr. Sutcliffe and now by Mr. Durst over the sea.

Mr. E. Gold surmised that when breaking waves occurred there would be a dissipation of energy and that the character of the turbulence might be quite different; indeed that new type of turbulence ought to be excluded from Mr. Durst's calculations.

NOTES AND NEWS

Clouds in Tanganyika

The cloud photographs facing pp. 253, 268 and 269 were taken by the late M. C. Gillman, who was Chief Engineer of the Tanganyika Railways.

The photograph facing p. 268 was taken at the end of April in the Dar-es-Salaam area and shows the typical heavy cumulus and cumulonimbus masses which form late in the day along the coast during the "rainy season" which marks the transition between the SE. and NE. monsoons of east Africa. As can be seen, the convection cloud is often associated with dense cirrus masses which are often the remains of the previous day's activity. Late in the night the convection cloud stratifies mainly in the medium and upper cloud levels so that the next morning is cloudy, sometimes in association with local

slight rain or drizzle. This, in fact, was the weather sequence on the morning that this photograph was taken. The surface wind throughout the day was mainly calm.

The photograph facing p. 269 was taken west of Dodoma, in central Tanganyika, during mid afternoon in December. These convection clouds, which further to the east were definitely fair-weather cumulus, have formed in the easterly airstream after forced ascent over the Saranda Scarp and thus have greater vertical development. Local very light showers may fall from these clouds during the late afternoon, but they quickly disperse towards dusk, and, even during the period of maximum heating the clouds are constantly dissolving and reforming. The general height of the plateau over the scarp is about 4,500 ft. and the clouds thus have a base which is usually about 8,000 ft. above sea level.

The description of the photograph facing p. 253 is given beneath it.

REVIEW

Wetter und Krankheiten. By Hellmut Berg. 8vo, 8 in. $\times$ 5 $\frac{3}{4}$ in., pp. iv+140, *Illus.*, H. Bouvier u. Co., Bonn. 1948. *DM* 6.50.

This book on weather and disease discusses nothing so obvious as the connexion between lumbago and draughts, or between sunstroke and sunshine. Its nearest approach to familiar things is found in a single paragraph on the common cold, pp. 75-7, dealing with the work of E. Flach, published in 1938.

One of Flach's diagrams shows a well marked decrease in the incidence of colds with increasing wind speeds, as if the wind helps to blow the germs away. Relative humidity appears to make little difference, but the plot of incidence against diurnal temperature range shows a striking minimum of colds when the range is less than 2°C. From this one might deduce that good health is favoured by persistent cloudiness. Curiously enough, no evidence is produced for, or against, the popular belief that low temperatures are the cause of colds—a belief long ago disproved by polar explorers but still, apparently, held by the man in the street, who refuses to keep off the street because nobody can persuade him he has got an infectious disease.

However, it is rarely that any connexion can be established between disease and isolated meteorological elements like temperature, humidity and so on. Most of the book discusses the influence of more generalised phenomena such as fronts, inversions, terrestrial magnetism and solar flares. These are brought into the investigation by use of the so-called “*n*-method” of taking the day of occurrence of a front, or what not, and seeing how the cases of illness are distributed about this day.

The results, set out in the chapter on “meteorotropic illnesses” the longest in the book, produce a bewildering miscellany which it would seem impossible at first to reduce to any sort of order. Infantile paralysis, for instance, is correlated with cold fronts in New York but not in Hesse, and rheumatism with subsidence before warm fronts or after cold fronts according to Flach, but with the actual passage of fronts according to Feige and Freund. Lung embolisms, say von Raettig and Nehls, happen on days of warm and cold fronts twice as often as they would if randomly distributed; but two other workers, investigating fatal cases, find that fronts have the opposite effect in

summer and no influence in winter, and that fatalities from lung embolism show some correlation with disturbances of terrestrial magnetism ; yet another worker finds that fronts have no demonstrable influence either way.

And so on, for more than twenty different diseases. One feels that any agreement between the various authorities, where it occurs, is as likely to be due to chance as to any real basis for their findings.

Fortunately the author, in a later chapter, sorts it all out for us on pages 93 and 98. Strong evidence is only apparent in the following cases :—

Death from all causes is strongly correlated with fronts of all kinds ; warm fronts are correlated with suicide and cold fronts with apoplexy, infantile paralysis and post-operative lung complications. Apoplectic stroke is least likely when barometric pressure is high. Influenza and rheumatism become more likely in the presence of inversions. Magnetic disturbances are correlated with tubercular haemorrhage from the lungs, and with eclampsia ; they are also liable to precede embolism by 4 or 5 days.

It seems questionable whether any of this great mass of statistical research can yet be put to any practical use, because the correlations are far from absolute. For instance, potential suicides at mental hospitals have to be watched all the time, and not merely when cirrostratus appears in the sky and AIRMET says there is a warm front coming. Berg gives particular attention to eclampsia, a disease characterised by convulsions at about the end of pregnancy. It can often be averted by taking strong measures as soon as premonitory symptoms appear. But what would an anxious husband say if the doctor, instead of getting on with his job, sat down beside the telephone and tried to contact the nearest magnetic observatory?

One wonders why some of the attempts at correlation, mentioned in the book, were ever undertaken. In each case the investigator must have made some wild guess as to how the phenomenon investigated could affect the disease, yet nowhere are we told what this guess was. However, once a relation is established hypotheses are put forward to account for it, and we are given several of these in the last two chapters. W. F. Peterson, who published a voluminous work "The Patient and the Weather" in America, is quoted as suggesting that fronts bring about their effects through alternate contraction and dilation of the vessels, presumably the blood vessels, in response to polar and tropical air respectively. Briefly, contraction reduces the oxygen supply to the tissues and impairs their resistance to disease ; pathogenic substances are thus created which easily circulate through the body when the vessels expand once more and their walls become more penetrable. We are not told of any biochemical evidence for their theory. Nor is any reason given why south-westerly winds of continental origin should stimulate cell growth in cancer, as Peterson believes they do. Several other hypotheses of various kinds are equally tentative.

Some experiments of E. Findeisen on the effects of weather on colloids are quoted as being significant, owing to the prevalence of the colloid state in living substance. The electrical resistance of a colloid solution of arsenious sulphide becomes gradually reduced with time, and Findeisen found that this reduction is hindered by showers and thunderstorms and accelerated by cold fronts and föhn winds.

“Föhn sickness,” characterized mainly by lassitude and other psychological symptoms, receives much attention from the author ; but any attempts to explain it must show why it suddenly ceases as the descending warm, dry air breaks through to ground level, and why sufferers cannot escape the symptoms even by staying indoors. Short-period fluctuations of atmospheric pressure, due to waves at the inversion, seem the most plausible explanation put forward so far. But lift attendants, bus drivers in hilly country, and sailplane pilots repeatedly climbing in thermals, subject themselves to pressure fluctuations of comparable period and amplitude without becoming föhn-sick.

One wonders whether the main influence of weather changes on the body is not brought about through the psychological factor, which is undoubtedly present in most diseases and especially in some of those discussed, such as gastric ulcer and asthma. Far greater changes of environment than some of those investigated, as Berg points out, can be experienced by merely going into or out of a room. If, as is generally accepted, the healthiest lives are those lived in the open air, then too much weather is better than too little. But nobody would think so from reading this book.

A. E. SLATER

OBITUARY

Mr. W. J. R. Pook, D.C.M.—We regret to announce the death of Mr. Pook which occurred at Barnes on July 24, 1949, after a long illness.

Mr. Pook entered the Meteorological Office in 1919 as a Clerk Assistant and at the time of his retirement in March 1949 had risen to the rank of Senior Experimental Officer. He served two tours of duty in the Middle East as a civilian, partly on administrative and partly on forecasting work. Mr. Pook saw service in France, Belgium and Italy with the Royal Artillery during World War I and was awarded the D.C.M. for conspicuous gallantry in the field. He formed part of the first meteorological contingent in France in World War II and for his services there was mentioned in despatches.

“Bill” Pook earned the highest regard of all members of the staff with whom he worked. His unflinching cheerfulness and the high standard he set himself were generally admired. His many unpublicised kindnesses to junior staff will long be remembered by many still remaining in the Office.

H. A. SCOTNEY

WEATHER OF JULY 1949

Mean pressure was between 1020 and 1025 mb. over a large area which included the Azores, Madeira and the southern parts of England and Ireland, and below 1010 mb. in the north-east of Canada. It was about 1015 mb. over most of Europe and North America. Deviations from the normal were small over Europe and North America, being generally positive over Europe and over the North Atlantic as far west as longitude 30°W., the excess being 5 or 6 mb. to northward and westward of the British Isles and in Scotland and Ireland.

Over the British Isles weather was mainly fine and warm with a thundery spell from the 13th to 17th, which affected most areas except north Scotland and broke the long period of dry conditions. Sunshine was generally above average, except in Ireland, most notably in south and south-west England.

Rainfall was well below average generally, but owing to intense falls during the thundery rains the normal was exceeded at a few irregularly distributed stations.

An anticyclone moved from the south-west of Ireland to the southern North Sea during the first three days and very fine warm weather prevailed. A trough of low pressure moving eastwards on the 4th brought small amounts of rain to most areas, and was followed by a cool northerly air stream. Maximum temperatures fell to the lower sixties and even, by the 7th, to 58°F. at Kew and Lympne, 57°F. at Felixstowe and Gorleston, and 55°F. at West Raynham. With anticyclonic conditions on the 8th and 9th, day temperatures rose again, subsequently reaching the higher eighties in many places, with a maximum of 90°F. on the 12th at several stations including Bristol and Camden Square. Meanwhile a depression situated over Spain on the 10th had deepened and moved north-westwards, turning north-east on the 13th and later east, to travel from the Scillies to the southern North Sea, from the 15th to the 18th. A secondary developed over the English Channel on the 13th and moved to the Irish Sea before filling up on the 14th, while associated troughs moved northwards over England and Wales from the 13th to 17th. During this period, with lower day temperatures, thundery conditions spread over most of the country. Rainfall distribution was irregular and sometimes very local; among the heavier falls were: 13th, 1.38 in. (out of a total of 1.72 in.) in 35 minutes at Elmdon and 2.40 in. in just over an hour at Holford, Somerset; 15th, 4.12 in. at March (Cambs.) and 3.39 in. at Afon Rheidol (Glam.); 16th, 2.77 in. at Chipping Norton and 2.60 in. at Crediton (Devon). Severe thunderstorms in the London area on the 16th caused damage and several deaths. A cooler north-westerly air stream established itself over the country on the 18th to 19th and drier conditions prevailed until nearly the end of the month. The troughs of a depression which passed to the north of Scotland gave some rain, mainly light, in the west and north on the 20th and 21st; but thereafter an irregular ridge of fairly high pressure, intersected only by weak troughs, maintained warm and fair weather, with very light winds, until the 26th; maximum temperatures again reached the eighties in many places and there were local thunderstorms in north-east England on the 25th. A feeble westerly current on the 26th was followed by more definite westerly conditions which persisted for the rest of the month. Slight rain or drizzle fell in many areas on the 27th, and subsequently there were frequent slight falls in the north and west, but the fine weather continued in the south until the 31st, when a depression moved north-east to the north of Scotland and the associated troughs travelled eastwards across the British Isles with light rain in all districts.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
England and Wales	92	36	+ 2.6	68	—5	121	46
Scotland	82	32	+ 1.5	65	—5	105	30
Northern Ireland . .	83	41	+ 1.3	77	—3	88	26

RAINFALL OF JULY 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	·84	35	<i>Glam.</i>	Cardiff, Penylan ..	1·31	43
<i>Kent</i>	Folkestone, Cherry Gdn.	·99	47	<i>Pemb.</i>	St. Ann's Head ..	2·00	77
"	Edenbridge, Falconhurst	·39	17	<i>Card.</i>	Aberystwyth ..	1·99	65
<i>Sussex</i>	Compton, Compton Ho.	·31	11	<i>Radnor</i>	Tyrmynydd ..	1·09	27
"	Worthing, Beach Ho.Pk.	·18	9	<i>Mont.</i>	Lake Vyrnwy ..	2·13	58
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	·24	12	<i>Mer.</i>	Blaenau Festiniog ..	4·88	57
"	Bournemouth ..	·38	18	<i>Carn.</i>	Llandudno ..	1·21	54
"	Sherborne St. John ..	1·96	88	<i>Angl.</i>	Llanerchymedd ..	1·99	70
<i>Herts.</i>	Royston, Therfield Rec.	2·22	88	<i>I. Man.</i>	Douglas, Borough Cem.	4·49	147
<i>Bucks.</i>	Slough, Upton ..	·71	37	<i>Wigtown</i>	Port William, Monreith	2·68	95
<i>Oxford</i>	Oxford, Radcliffe ..	·91	38	<i>Dumf.</i>	Dumfries, Crichton R.I.	3·17	97
<i>N'hant.</i>	Wellingboro', Swanspool	1·49	65	"	Eskdalemuir Obsy. ..	2·64	64
<i>Essex</i>	Shoeburyness ..	·20	11	<i>Roxb.</i>	Kelso, Floors ..	2·39	91
<i>Suffolk</i>	Campsea Ashe, High Ho.	1·25	54	<i>Peebles</i>	Stobo Castle ..	2·08	72
"	Lowestoft Sec. School ..	·48	21	<i>Berwick</i>	Marchmont House ..	2·37	78
"	Bury St. Ed., Westley H.	·89	36	<i>E. Loth.</i>	North Berwick Res. ..	1·91	74
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·25	88	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	2·71	96
<i>Wilts.</i>	Bishops Cannings ..	1·43	57	<i>Lanark</i>	Hamilton W. W., T'nhill	1·58	55
<i>Dorset</i>	Creech Grange ..	·67	27	<i>Ayr</i>	Colmonell, Knockdolian	1·21	38
"	Beaminster, East St. ..	1·57	60	"	Glen Afton, Ayr San ..	2·07	49
<i>Devon</i>	Teignmouth, Den Gdns.	1·38	59	<i>Bute</i>	Rothsay, Ardenraig	2·60	66
"	Cullompton ..	2·12	79	<i>Argyll</i>	L. Sunart, Glenborrodale	3·15	68
"	Barnstaple, N. Dev. Ath.	1·75	65	"	Poltalloch ..	2·02	49
"	Okehampton, Uplands	2·13	66	"	Inveraray Castle ..	3·63	73
<i>Cornwall</i>	Bude School House ..	1·83	75	"	Islay, Eallabus ..	·85	25
"	Penzance, Morrab Gdns.	1·51	56	"	Tiree ..	1·44	40
"	St. Austell, Trevarna ..	2·60	78	<i>Kinross</i>	Loch Leven Sluice ..	2·36	82
"	Scilly, Tresco Abbey ..	1·18	53	<i>Fife</i>	Leuchars Airfield ..	3·02	116
<i>Glos.</i>	Cirencester ..	1·50	58	<i>Perth</i>	Loch Dhu ..	..	..
<i>Salop.</i>	Church Stretton ..	2·55	97	"	Crieff, Strathearn Hyd.	1·49	50
"	Cheswardine Hall ..	1·62	60	<i>Perth</i>	Pitlochry, Fincastle ..	1·55	58
<i>Worcs.</i>	Malvern, Free Library	2·19	96	<i>Angus</i>	Montrose, Sunnyside ..	1·96	75
<i>Warwick</i>	Birmingham, Edgbaston	2·77	119	<i>Aberd.</i>	Braemar ..	1·59	62
<i>Leics.</i>	Thornton Reservoir ..	4·63	187	"	Dyce, Craibstone ..	2·45	81
<i>Lincs.</i>	Boston, Skirbeck ..	2·74	125	"	Fyvie Castle ..	2·53	78
"	Skegness, Marine Gdns.	1·77	81	<i>Moray</i>	Gordon Castle ..	1·70	53
<i>Notts.</i>	Mansfield, Carr Bank ..	3·60	137	<i>Nairn</i>	Nairn, Achareidh ..	1·78	70
<i>Derby</i>	Buxton, Terrace Slopes	2·14	54	<i>Inv's</i>	Loch Ness, Foyers ..	1·09	36
<i>Ches.</i>	Bidston Observatory ..	1·86	72	"	Glenquoich ..	5·25	82
<i>Lancs.</i>	Manchester, Whit. Park	1·76	53	"	Fort William, Teviot	2·32	47
"	Stonyhurst College ..	3·08	80	"	Skye, Duntuilm ..	2·11	56
"	Blackpool ..	2·58	88	<i>R. & C.</i>	Ullapool ..	1·68	55
<i>Yorks.</i>	Wakefield, Clarence Pk.	3·43	136	"	Applecross Gardens ..	2·61	65
"	Hull, Pearson Park ..	1·64	70	"	Achnashellach ..	5·08	104
"	Felixkirk, Mt. St. John	2·35	86	"	Stornoway Airfield ..	1·39	48
"	York Museum ..	2·42	96	<i>Suth.</i>	Lairg ..	..	..
"	Scarborough ..	1·37	56	"	Loch More, Achfary ..	2·55	48
"	Middlesbrough ..	1·36	53	<i>Caith.</i>	Wick Airfield ..	·69	26
"	Baldersdale, Hury Res.	2·77	87	<i>Shetland</i>	Lerwick Observatory ..	1·69	74
<i>Nor'l'd.</i>	Newcastle, Leazes Pk. ..	1·99	78	<i>Ferm.</i>	Crom Castle ..	3·04	87
"	Bellingham, High Green	2·18	66	<i>Armagh</i>	Armagh Observatory ..	2·73	94
"	Lilburn Tower Gdns. ..	2·38	96	<i>Down</i>	Seaforde ..	3·07	96
<i>Cumb.</i>	Geltsdale ..	2·72	79	<i>Antrim</i>	Aldergrove Airfield ..	1·67	60
"	Keswick, High Hill ..	1·91	50	"	Ballymena, Harryville ..	2·15	63
"	Ravenglass, The Grove	4·12	110	<i>L'derry</i>	Garvagh, Moneydig ..	2·24	69
<i>Mon.</i>	Abergavenny Larchfield	·63	25	"	Londonderry, Creggan	2·49	68
<i>Glam.</i>	Ystalyfera, Wern House	1·76	38	<i>Tyrone</i>	Omagh, Edenfel ..	2·56	75

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, MARCH 1949

STATIONS	PRESSURE			TEMPERATURES						REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE		
	Mean of day M.S.L.	Diff. from normal	Absolute		Mean values							Total	Diff. from normal	Days	Daily mean	Per- centage of possible	
			Max.	Min.	°F.	°F.	Max.	1 2									Wet bulb
								°F.	°F.								
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	oktas	in.	in.	hr.	%		
1021.8	+8.9	63	29	48.0	36.1	42.1	-1.0	37.8	77	5.7	0.92	-0.77	8	3.3	28		
Gibraltar ..	-0.9	72	48	63.5	54.7	59.1	+1.5	54.6	78	5.5	2.69	—	11	4.8	40		
Malta ..	+0.9	71	36	58.7	47.1	52.9	-4.2	50.9	69	4.8	1.71	+0.02	12	7.3	61		
St. Helena ..	-1.7	82	60	75.8	63.3	69.5	+4.0	63.7	97	6.7	4.14	—	20	—	—		
Lungi, Sierra Leone	—	91	71	87.6	75.0	81.3	—	74.3	77	4.5	0.00	—	0	8.1	67		
Lagos, Nigeria	+0.2	96	68	93.2	74.1	83.7	+0.3	78.8	78	6.7	1.84	—	6	5.2	43		
Kaduna, Nigeria ..	—	99	61	94.7	68.2	81.5	-0.1	64.5	35	3.7	0.27	-0.27	2	8.1	67		
Chileka, Nyasaland	+0.1	96	60	83.7	66.7	75.2	+1.7	66.9	70	5.0	3.99	-2.60	8	6.0	49		
Lusaka, Rhodesia ..	-0.1	91	56	81.7	62.1	71.9	+1.6	63.9	81	6.1	4.14	-2.07	10	6.6	54		
Salisbury, Rhodesia	-0.1	86	51	77.9	58.0	67.9	+0.2	60.3	74	4.8	1.95	-2.75	11	6.3	52		
Cape Town...	-0.7	102	51	81.7	60.6	71.1	+3.0	57.7	59	2.4	0.23	-0.65	3	—	—		
Palmietfontein, S. Africa	—	82	40	75.5	53.3	64.4	—	56.2	79	4.0	1.94	—	6	7.3	—		
Mauritius ..	-0.3	99	60	94.2	71.7	82.9	+2.7	72.0	64	1.5	1.28	-0.10	1	8.8	73		
Calcutta, Alipore Obsv.	-0.7	99	67	88.8	73.3	81.1	+1.6	71.8	68	1.2	0.00	-0.02	0	8.4	70		
Bombay ..	+0.3	101	69	92.6	73.0	82.8	+1.7	74.2	75	1.7	0.00	-0.34	0	10.8	90		
Madras ..	+0.4	92	70	88.7	74.0	81.3	-0.5	75.1	83	2.3	6.08	+1.80	7	9.6	79		
Colombo, Ceylon ..	0.0	94	73	90.1	75.0	82.5	+1.3	76.2	78	4.7	2.91	-4.49	10	—	—		
Singapore ..	+0.5	78	58	70.8	62.6	66.7	+3.4	62.9	84	—	0.17	-2.77	6	2.6	22		
Hongkong ..	+1.6	82	50	73.8	63.7	68.7	-0.6	64.9	79	5.9	3.80	-1.18	18	4.8	39		
Sydney, N.S.W. ..	+1.1	96	46	71.4	55.5	63.5	-1.0	57.9	73	6.1	5.25	+3.07	13	4.4	36		
Melbourne ..	+1.6	97	48	77.1	56.4	66.7	-3.2	57.3	49	3.0	0.05	-0.97	2	8.7	71		
Adelaide ..	+0.8	103	52	83.3	60.9	72.1	+0.9	67.2	68	2.4	0.72	-0.09	5	—	—		
Perth, W. Australia	-0.5	87	61	80.0	68.1	74.1	-0.2	67.2	68	5.4	7.54	+1.77	21	5.3	43		
Coalgardie ..	—	87	44	66.9	49.1	58.0	-1.3	51.7	64	5.3	1.14	-0.56	7	6.2	50		
Brisbane ..	+3.7	73	41	65.4	51.2	58.3	-1.0	54.4	74	4.8	2.54	-0.70	8	6.9	56		
Hobart, Tasmania	+1.2	90	72	84.9	74.1	79.5	-0.6	76.6	87	6.4	21.37	+6.88	28	4.6	38		
Wellington, N.Z. ..	0.0	90	72	86.6	74.0	80.3	-0.1	77.4	82	5.9	14.21	+0.50	26	6.3	52		
Suva, Fiji ..	+0.2	91	65	87.3	69.1	78.2	+1.1	70.5	69	1.4	0.62	-0.40	4	9.0	75		
Apia, Samoa ..	-0.6	88	70	86.0	72.0	79.0	-1.2	72.0	74	4.0	1.00	-1.66	7	—	—		
Kingston, Jamaica	—	65	10	39.3	25.6	32.5	+2.9	26.2	73	6.2	2.17	-0.24	15	3.9	33		
Grenada, W. Indies	-1.8	40	-17	24.7	6.9	15.8	+0.8	10.1	89	4.7	0.69	-0.47	6	4.3	36		
Toronto ..	+0.2	51	6	37.0	23.8	30.4	+2.0	26.2	84	5.7	4.09	-0.45	20	3.9	33		
Winnipeg ..	-3.0	57	27	50.3	35.6	42.9	-0.6	37.0	87	5.1	2.22	-0.21	18	4.7	39		
St. John, N.B. ..	-0.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Victoria, B.C. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		

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WEATHER FORECASTS BY TELEVISION

By E. G. BILHAM, B.Sc., D.I.C.

On the evening of July 29 television viewers in Great Britain were able to see and hear a new feature in the programme broadcast from Alexandra Palace, namely a weather report and forecast illustrated by charts. This feature has since been included as the last item of the television programme each evening.

The weather report begins with a brief summary of the weather of the day, illustrated by a chart (see Fig. 1, p. 278) headed "Weather this evening" showing in a very generalised sort of way the weather over the British Isles at 5 p.m. This is followed after a brief pause by a second chart (Fig. 2), headed "Weather expected to-morrow morning", with spoken text indicating the main features of next day's weather over the country as a whole. Next follows a more detailed forecast for London and south-east England covering the period 8 a.m. to midnight. The report concludes with a "Further Outlook" for London and south-east England. The actual text of the spoken script which accompanied the charts on July 29 (the Friday preceding August Bank Holiday) was as follows :—

Television Forecast, Friday, July 29, 1949

Here is the Meteorological Office weather report and forecast. The first chart shows the general weather situation this evening.

A north-westerly air stream covers the British Isles. Weather is fine generally apart from scattered showers in Scotland and northern England. It has been fine all day in the south-eastern districts of England, where temperature has exceeded 70 degrees. In northern and western districts there have been bright intervals and scattered showers.

By tomorrow morning the weather chart is expected to look like this.

It will be fine over the whole country in the morning, and the fine weather will last all day in most districts. Rain moving east from the Atlantic will reach Ireland and west Scotland during the afternoon or evening.

Here is the forecast for London and south-east England for to-morrow, 8 a.m. to midnight:—

Fair and rather warm, with afternoon temperature 75 degrees or slightly higher.

Finally, here is the outlook for London and south-east England for Sunday and Monday.

Occasional rain on Sunday but perhaps only in small amounts. Bright intervals on Monday with a cool breeze. A chance of a few showers in the afternoon and evening.

The planning of this television feature gave rise to a number of problems. The first trials showed that it was quite impossible to televise successfully

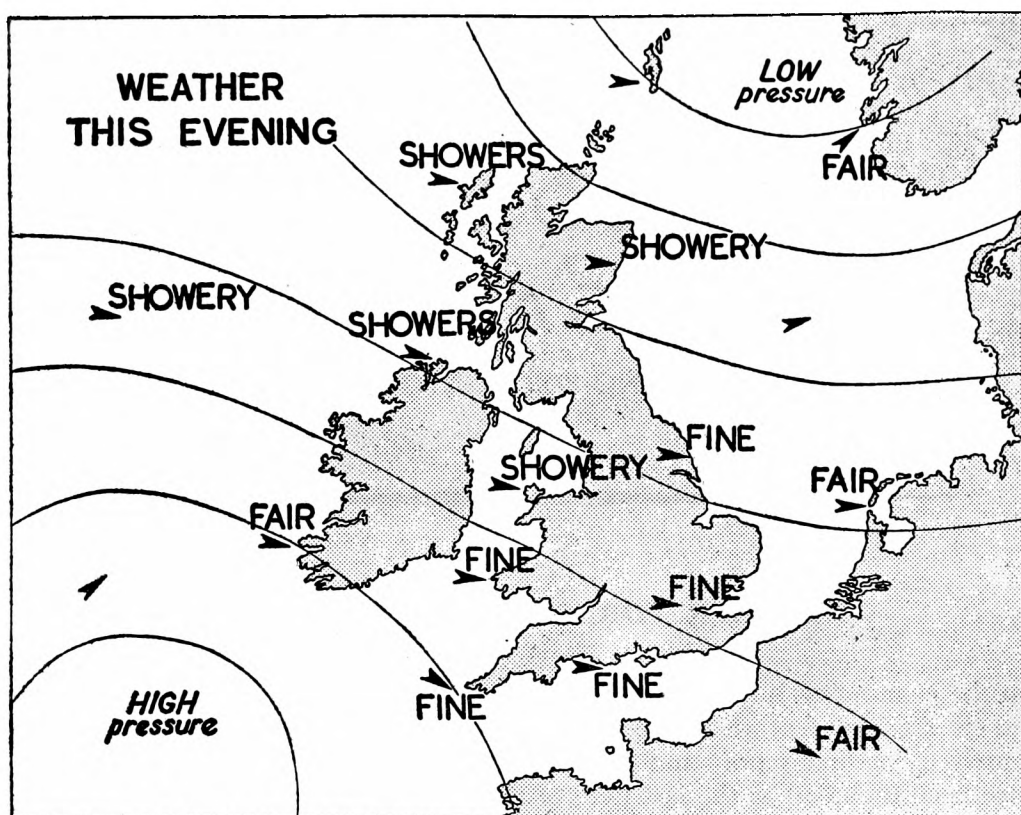


FIG. 1—FIRST CHART FRIDAY, JULY 29TH, 1949, 5 P.M.

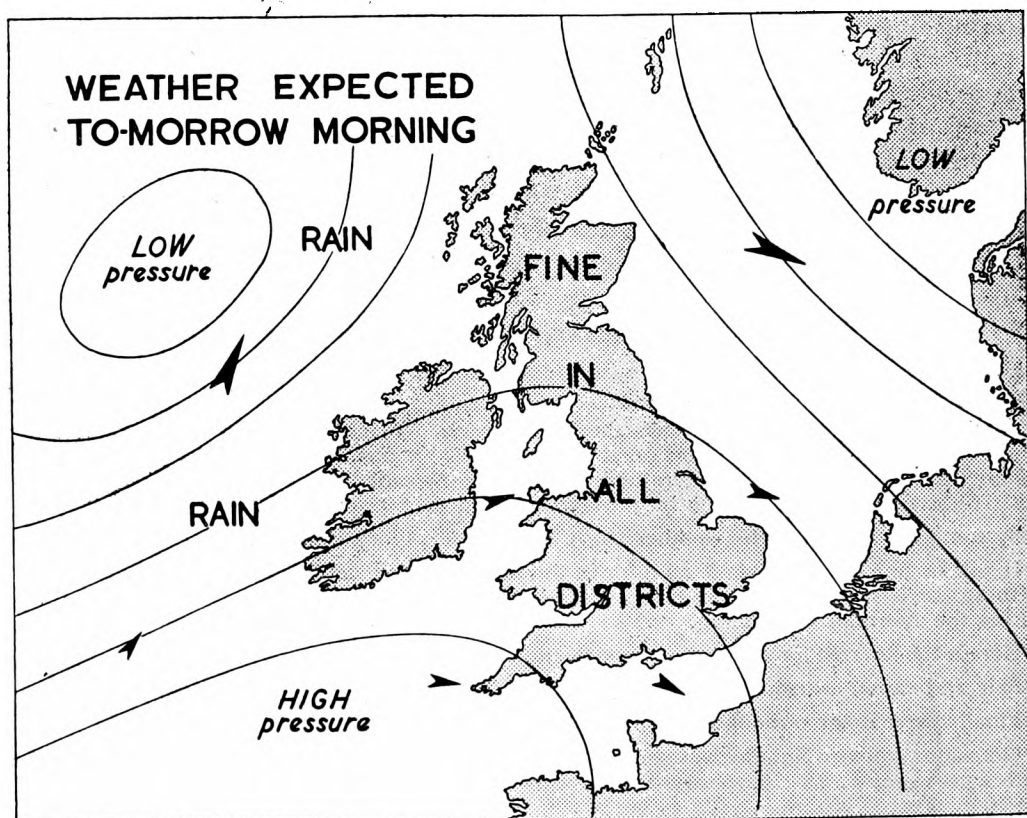


FIG. 2—SECOND CHART FRIDAY, JULY 29TH, 1949.

anything resembling an ordinary synoptic chart with the usual plottings of wind, weather and temperature. It was essential that the viewer should be able to take in, without effort, what he saw on the screen, and he could not be expected to memorise symbols or to strain his eyes by trying to read small lettering or figures. After several trials it became manifest that the sort of chart required was one in which the main weather features over relatively large areas were indicated by boldly printed legends without attempting to indicate small local variations. In the charts as now televised the weather legends are in half-inch block lettering. Wind directions are shown by very bold arrows, and the strength of the wind is roughly indicated by using a long arrow for winds of Beaufort force 6 or more and a shorter arrow for force 5 or less. Isobars are shown at intervals of 4 mb. and italic lettering is used to indicate centres of high and low pressure. Land areas are distinguished from sea areas by tinting the former in a carefully selected shade of light grey.

For technical reasons black lines on a white background do not televise satisfactorily, and paper is unsuitable because it tends to bend and cockle under the heat of the illuminating lamps. The charts used are therefore specially printed on light grey cardboard. As a further example of the technical complications it may be mentioned that this short item, lasting only two or three minutes, necessitates the use of three television cameras, one for the announcer and one for each of the two charts.

As an introduction to the series Dr. J. M. Stagg gave a short talk, illustrated with charts in which he explained the main weather features associated with high and low pressure systems, and how forecasting depends primarily on estimating the movements and developments of these systems.

TEMPERATURE FORECASTS FOR THE BRITISH ISLES

The general weather forecasts for the British Isles, which are supplied to the Press and the B.B.C. by the Meteorological Office as a daily routine, lay some emphasis on the level of temperature likely to be experienced. This information is of particular interest and importance when conditions favour frost in winter or spring, and almost equally so when very warm or hot weather is anticipated in summer.

The degree of warmth or cold expected is expressed by the use of descriptive terms, or by specifying the actual temperature likely to occur, or by a combination of the two methods. When the method of giving actual values is adopted it is usual either to specify a range of, say, 5 degrees, to indicate the general level of temperature expected (*e.g.* temperatures will be between 55 and 60°F.) or to state the value expected to be reached (*e.g.* temperatures will reach 60°F. in the London area).

When descriptive terms are employed they are selected from the following :—

hot, warm, mild, cool, cold

qualified as necessary by “rather” or “very”. The expression “normal for the time of year” is also used. These descriptive terms are defined in relation solely to the normal temperature for the time of year, no account being taken of any other meteorological factor such as the wind strength, or the humidity, which may subjectively influence the particular sensation of warmth or coldness experienced by an individual exposed to a specified air temperature.

The graduation of terms from that signifying the highest values above the normal to that signifying the lowest values below, for each season of the year, together with the associated departures from normal, is as follows :—

(a) *Summer—mid May to mid September*

Term	Relation of temperature to normal °F.
Very hot	More than 20° above normal
Hot	16—20° above
Very warm	11—15° above
Warm	6—10° above
Rather warm	3—5° above
Normal	2° above to 2° below normal
Rather cool	3—5° below
Cool	6—9° below
Very cool	10—15° below
Cold	More than 15° below normal

(b) *Spring—mid March to mid May,*

Autumn—mid September to October 31

Term	Relation of temperature to normal °F.
Very warm	More than 12° above normal
Warm	8—12° above
Rather warm	3—7° above
Normal	2° above to 2° below normal
Rather cold	3—7° below
Cold	8—15° below
Very cold	More than 15° below normal

(c) *Winter—November 1 to mid March*

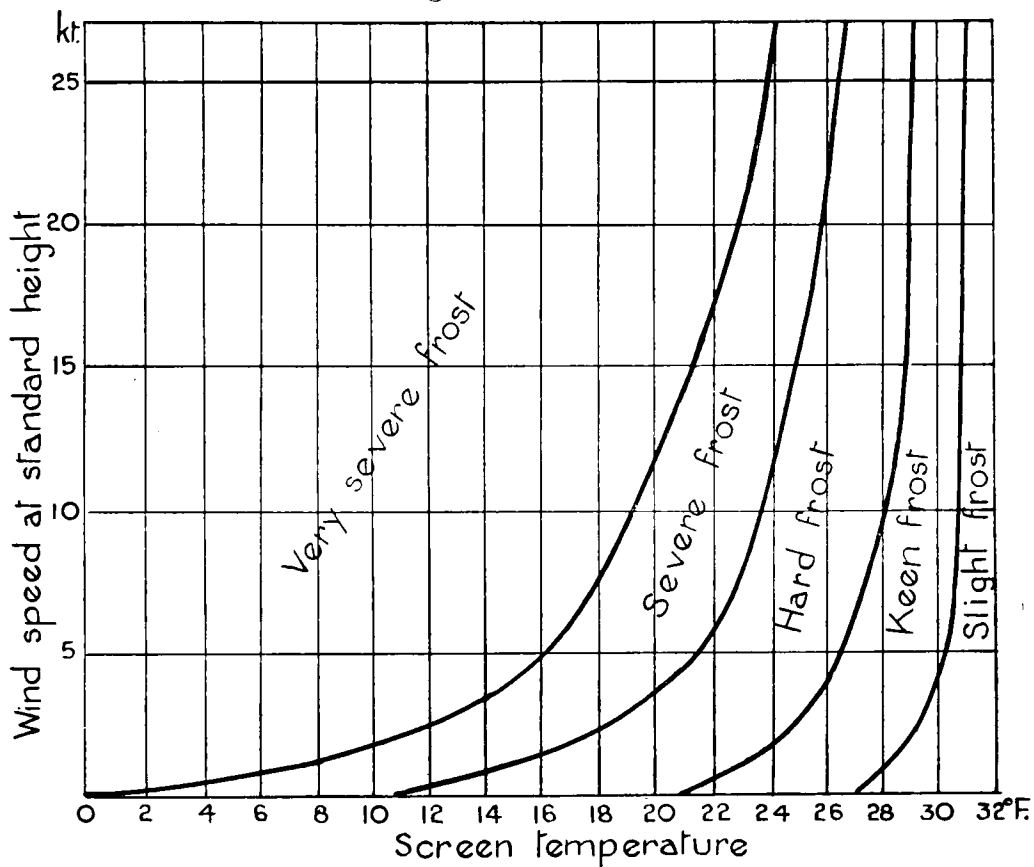
Term	Relation of temperature to normal °F.
Very mild	More than 10° above normal
Mild	3—9° above
Normal	2° above to 2° below normal
Rather cold	3—5° below
Cold	6—10° below
Very cold	More than 10° below normal

When a comparison is being made between temperature conditions expected and those recently experienced, terms such as colder, cooler, milder, warmer, are employed.

Certain special conditions of temperature and humidity are implied by the terms close, muggy and raw, and these are used, when appropriate, with the following meanings :—

- close = temperature normal or above normal for the season, with high humidity, a cloudy or overcast sky, and a calm or light wind ; oppressive.
- muggy = warm and damp but not necessarily oppressive.
- raw = cold and damp, sometimes with fog.

For frost forecasting a special set of descriptive terms is employed. The relationship between these terms and the expected temperature involves the strength of the wind, in view of the much more damaging effect of low air temperatures or frost with strong winds than with light winds or calms. The classification is shown in the diagram.



The limits within which each descriptive term applies are shown by the curved lines. The values corresponding to calm air and to a wind speed of 20 kt. are given in the table below.

Term	Corresponding screen temperature	
	Calm air °F.	Wind speed 20 kt. °F.
Slight frost	32—27	32—31
Keen frost	26—21	30—29
Hard frost	20—11	28—26
Severe frost	10—0	25—23
Very severe frost	Below 0	Below 23

For other wind speeds the appropriate term is derived by plotting the point corresponding to the forecast temperature and wind speed on the diagram.

The term “sharp frost” is not included in the classification. It is normally used only in connexion with night frost and low grass-minimum temperatures (below 25°F.) and generally with clear skies. The screen temperature is not generally very low. A screen temperature of 30°F. and a grass minimum of 18°F. would be termed a sharp frost and the correct description of these conditions is “sharp ground frost with slight air frost”.

HALO PHENOMENA OF JULY 20, 1949

E. W. BARLOW B.Sc.

About 1030 B.S.T. on July 20, Mr. E. V. Newnham noticed that halo phenomena were in evidence and some members of the staff of the Meteorological Office at Harrow went on to the roof to view the display, which lasted till about 1100. The phenomena seen were the halo of 22° , the two mock suns of 22° , very vividly coloured, a large part of the mock sun ring (parhelic circle) and two white mock suns on this ring, as shown in Fig. 1.

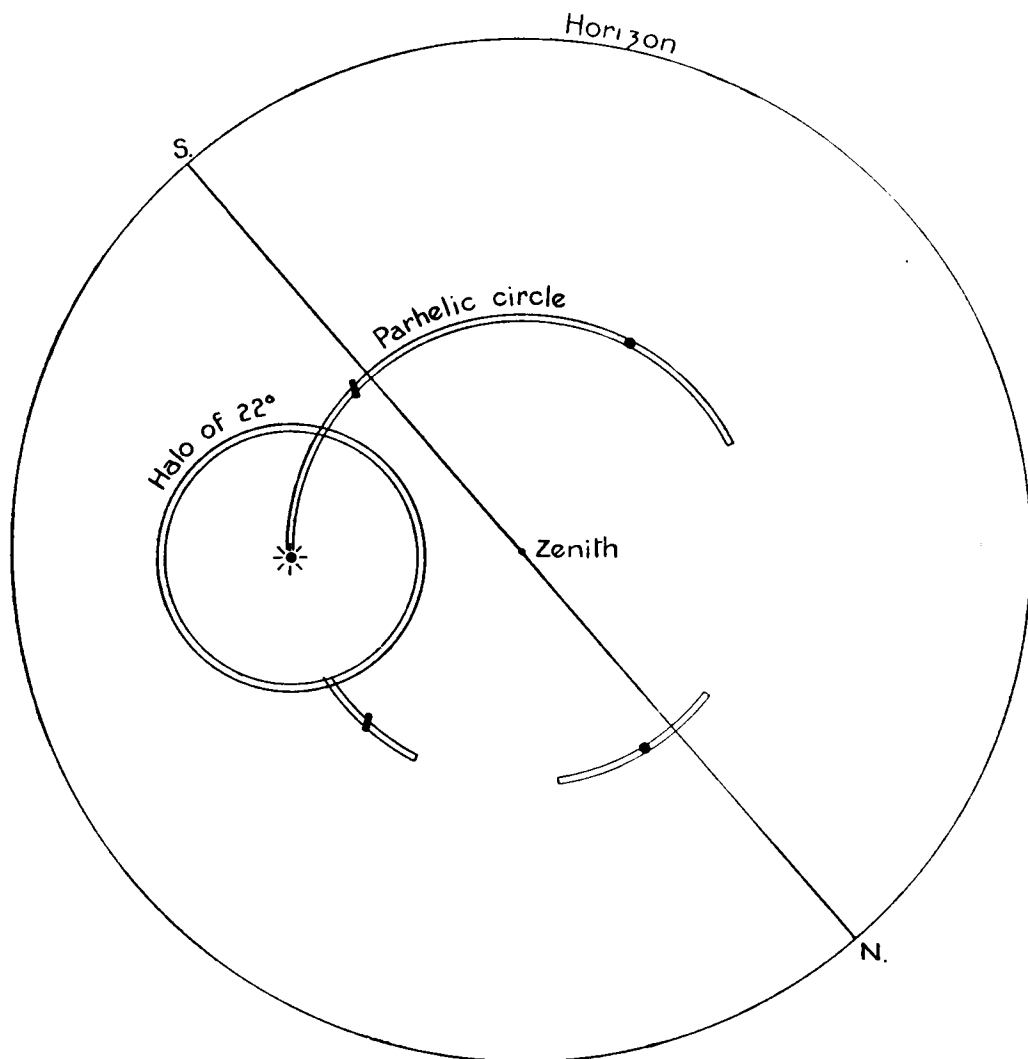


FIG. 1—HALO PHENOMENA, JULY 20, 1949, 1048 B.S.T.

Sun's altitude 50° , azimuth 129°

Four mock suns are shown on the parhelic circle

The sky was most favourable for halo production on the west side of the sun, with a very uniform veil of cirrostratus, so thin that the blue of the sky was hardly dimmed, and the bright white western part of the parhelic circle stood out in strong contrast. Some very delicate threads of cirrus were superimposed and these crossed the parhelic circle almost vertically. Elsewhere, the cirrostratus was thicker or altocumulus was present. The halo complex afforded some points of special interest.

Halo of 22°.—During the period of my own observation, from 1040 to 1100, this, the “common halo”, was the least persistent and striking of all. I never saw it complete at any one time; it was rather faint and was narrower than usual, but with more evidence of colour than it generally has. The arc of upper contact was not seen.

Parhelia of 22°.—The sun's altitude being 50°, the parhelia were about 10° distant from the halo of 22°. They presented a very remarkable aspect. In all my many previous observations of mock suns I have never seen anything approaching the brilliancy and purity of colour shown on this occasion. The colours were almost of spectrum purity, a quality which the circumzenithal arc, alone of all halo phenomena, normally exhibits. The blue end of the spectrum, which is rarely seen at all in a mock sun, was very clear. Furthermore the purity of colour, implying an absence of overlapping images, resulted in each mock sun being much smaller than usual, and instead of the normal rounded form each was oblong in shape, with the length of the oblong inclined at about 45° to the parhelic circle, as shown in Fig. 1. It might perhaps be claimed that the linear projections of the mock sun outside the parhelic circle were the beginnings of the very rare arcs of Lowitz. For a short time the western parhelia developed the well known brilliant white tail along the parhelic circle; this soon faded, without any change in the general intensity of the parhelic circle. The eastern parhelia showed the same vivid colour as the western one, and the same shape and inclination, but was often partly obscured by cloud variation.

Parhelic circle.—This was very luminous, with very sharp edges; it usually appears more or less diffuse. It passed through the western side of the halo of 22° right up to the sun: more frequently this part of the circle is absent. The part opposite the sun and most of the eastern side were not seen at all.

Parantheria of 120° (sometimes called parhelia).—The contrast between the brightly coloured oblong parhelia of 22° and the bright white round one further along the parhelic circle was very spectacular. A rough estimate of the distance between the two, compared to the known distance of the parhelia of 22° from the sun, placed the parantheria as about 120° in azimuth from the sun, as measured round the parhelic circle. Mock suns in approximately this position, on either side of the sun, have not infrequently been seen by various observers. For a short time Mr. Newnham and myself saw a short segment of the eastern side of the parhelic circle, with a parantheria in the middle. This was relatively faint, the cloud being so thick that one would not have expected to see any halo phenomenon on it. The parantheria was at the same distance from the sun as the western one, as nearly as could be judged.

Mr. D. F. Bowering, at Croydon Airport, saw the halo and parhelia of 22° and the parhelic circle.

Mr. W. Holt, at St. Chads Secondary Boys' School, Tilbury, Essex, saw the same phenomena as those visible at Harrow. In a letter to the Meteorological Office, he states that a rippling movement was seen to pass over the parhelic circle a number of times. At times the rippling movement passed over the whole of the circle, as shown in Fig. 2. At other times the ripples travelled round the circle itself, as shown in Fig. 3. This movement was also seen in the opposite direction. This is a very remarkable observation, of which it is difficult to find an explanation, since the only instances of the rippling of halo phenomena

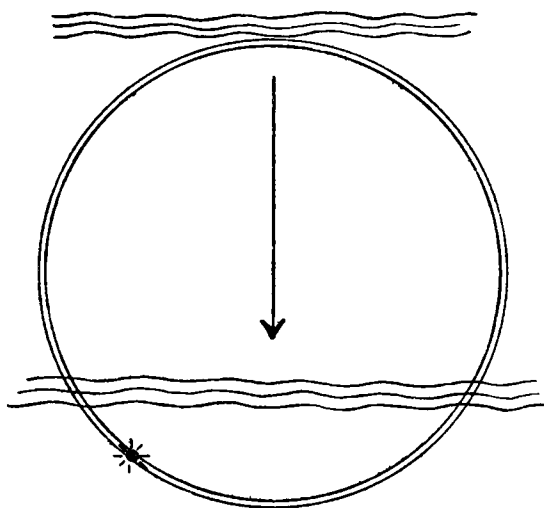


FIG. 2

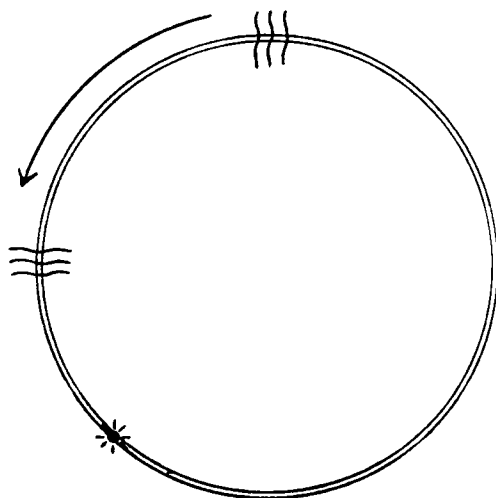


FIG. 3

previously recorded occurred during the wars of 1914-18 and 1939-45, when the phenomenon was explained as being due to the waves of alternate compression and expansion of air produced by heavy gunfire or explosions.

MEASUREMENTS OF WIND AND TEMPERATURE UP TO 100,000 FT. BY RADIO-SONDE AND RADAR

By F. J. SCRASE, M.A., Sc.D., F.Inst. P.

Summary.—The first observations of upper wind and air temperature up to 100,000 ft. to be made in this country by means of radio-sonde and radar have confirmed the occurrence, at these high levels, of easterly winds in summer and winds from a westerly quarter in winter. The lowest temperatures measured (in midsummer) occurred at about 50,000 ft., there being a rise from about -70°F. (-57°C.) at that height to -40°F. (-40°C.) at 100,000 ft. Some of the soundings indicated multiple tropopause.

Introduction.—In the autumn of 1945 the Gassiot Committee of the Royal Society expressed the view that a need would shortly exist for sounding balloons capable of carrying radio-sondes to a height of 30 Km. (100,000 ft.). The development of such balloons has been pursued by the Instruments Development Division of the Meteorological Office in co-operation with the Research and Development Establishment, Ministry of Supply, and the Guide Bridge Rubber Company. A brief account of the earlier work on the problem was given by Ashford and Harrison^{1*}. The average height to which a standard 500-gm. expanding rubber-latex sounding balloon will carry a radio-sonde weighing 1,500 gm. is about 60,000 ft. Ashford and Harrison reported the results of some trials with pairs of 700-gm. balloons in tandem, which reached heights averaging about 75,000 ft. A few ascents were also made with some experimental balloons weighing 4,500 gm. but these did not give any marked increase in height; moreover, the large size was a disadvantage both in construction and in launching. In the course of these trials it was found that, at the high levels reached, the windmill-operated switch of the radio-sonde ceased to function satisfactorily.

*These numbers refer to the list of references on p. 289.

Although great heights have been obtained in other countries by using non-extensible balloons made of plastic film, the size and fragile nature of such balloons limit their use to comparatively calm conditions. It was decided therefore to continue the development of rubber-latex balloons to reach heights of 100,000 ft. and of a size convenient for handling at normal radio-sonde stations.

An experimental batch of 2,000-gm. balloons was produced and after some of these had been used for inflation tests on the ground the remainder were used for flight trials. Seven out of nine ascents exceeded 95,000 ft. and the highest reached 102,300 ft. It is believed that the results obtained are the first balloon soundings of temperature and wind at these heights to be obtained by radio-sonde and radar in this country and it is the purpose of this note to put these results on record. A more detailed discussion of the balloon performance will be dealt with in a separate paper, but it may be of interest to mention here that the successful balloons expanded from an initial (unstretched) diameter of 6.5 ft. to just over 30 ft. at burst.

Ascents.—The first two ascents were made at Kew Observatory and were confined to the measurement of upper wind by radar observations of azimuth, elevation and slant range of a corner reflector attached to the balloon. The reflector was of the metallised nylon mesh type described by Ashford and Ferrer² and weighed about 800 gm. In the other ascents, which were made at the Meteorological Office aerological stations at Larkhill and Downham Market, the balloons carried both radio-sonde and radar reflectors. The radio-sondes, which normally transmit pressure, temperature and humidity readings, in turn, were adapted to indicate temperature only, thus avoiding the need for the windmill switch. To avoid possible temperature errors due to solar radiation falling on the temperature units the radio-sonde ascents were made at night. Extra lagging was provided for the standard radio-sonde batteries to guard against possible failure due to the longer time they would spend in the stratosphere.

Operational details for these soundings are included in Table I. The heights computed from the radar observations are corrected for the curvature of the earth. Occasions when winds were not strong were chosen for the ascents so as to avoid the balloons going beyond the radar range, about 66,000 yd. Observations were made every five minutes up to 30,000 ft. but above that height the radar observations were made every minute and the temperature readings every half minute. Wind speed and direction and temperature were computed for every 5,000 ft. from 30,000 ft. upwards and it is these data which are plotted in Fig. 1. The Downham Market ascent on July 1 is omitted from the diagram since the results were very little different from those on June 29. It will be noted that the two ascents on July 6 at Larkhill and Downham Market were practically simultaneous; the latter station is about 110 miles north-east of the former. The synoptic conditions for all the soundings were more or less anticyclonic.

Wind up to 100,000 ft.—The most noticeable features of the observations of wind are the large veer in direction, exceeding 100° , which occurred between 50,000 and 70,000 ft. and the comparative steadiness of direction above the latter height. A minimum in the wind speed also occurred between these heights. Table I summarises the quantitative information on these features.

TABLE I—SOME NOTICEABLE FEATURES ON HIGH BALLOON ASCENTS

	Date	Hour	Duration	Maximum height	Main change in wind direction*	Minimum speed*	Speed at 100,000 ft.	Minimum Temperature*	Tropopause Temperature*
		G.M.T.	min.	ft.		kt.	kt.	°F.	°F.
Kew	1949 Mar. 24	1400	82	102,000	130° to 230° (45) (65)	17 (50)	20	—	—
Kew	Apr. 19	1400	75	102,300	310° to 90° (50) (75)	6 (57)	12	—	—
Downham	June 29	2200	81	100,120	340° to 85° (50) (70)	8 (63)	26	-79 (42)	-79 (42)
Downham	July 1	2200	83	101,690	330° to 80° (55) (70)	10 (67)	28	-76 (41)	-76 (41)
Larkhill	July 2	2200	67	96,900	310° to 80° (50) (65)	6 (63)	24	-75 (53)	-70 (40)
Larkhill	July 6	2200	76	97,600	270° to 90° (55) (65)	7 (55)	23	-62 (56)	-60 (33)
Downham	July 6	2200	87	97,880	310° to 90° (50) (65)	0 (55)	24	-63 (60)	-62 (33)
Means for last 5 ascents					310° to 85° (52) (67)	6 (61)	25	-73 (50)	-71 (40)

*Heights of these values are given in thousands of feet in brackets.

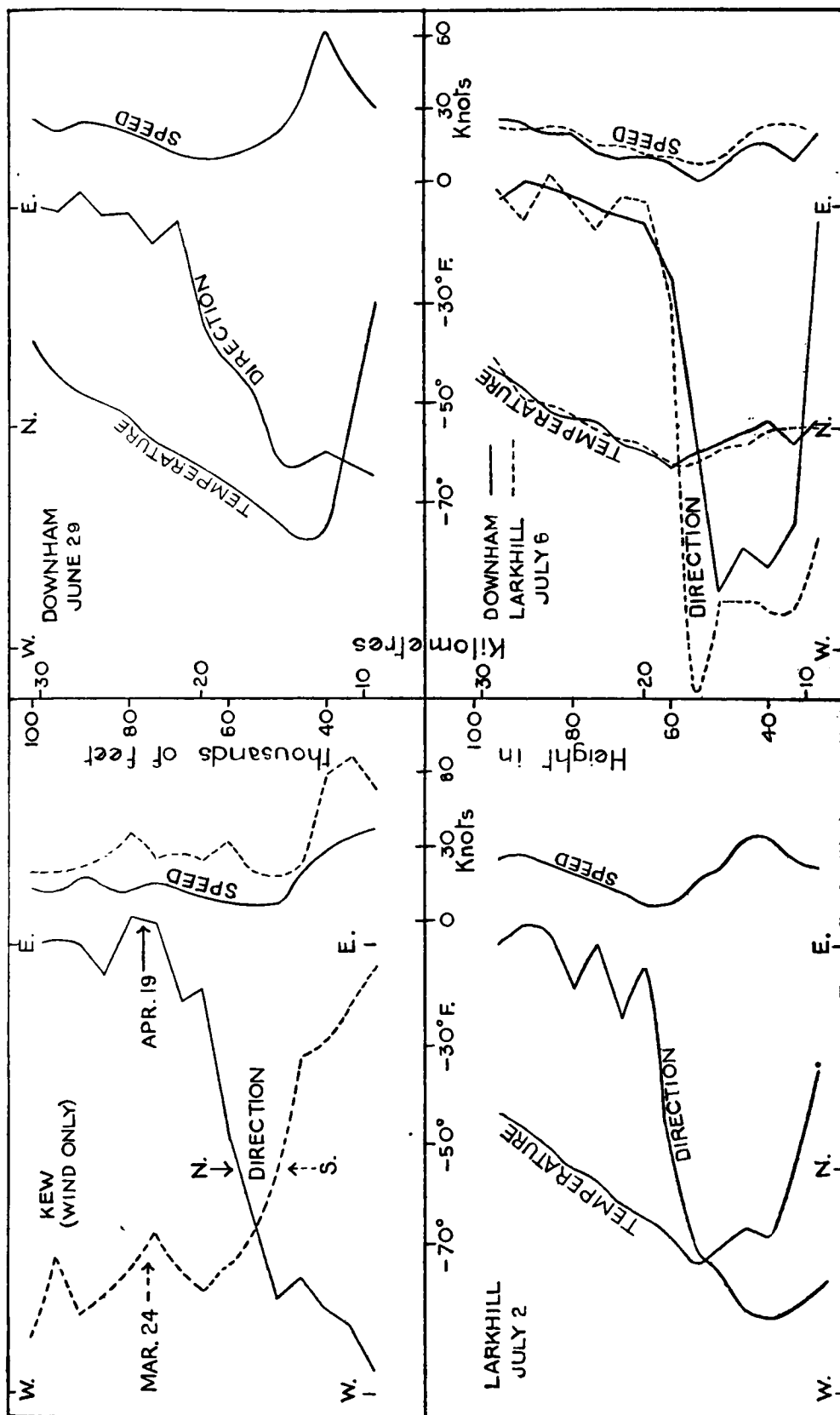


FIG. 1—RADIO-SONDE AND RADAR OBSERVATIONS OF WIND AND TEMPERATURE UP TO 100,000 FT.

The soundings provide good confirmation of the "monsoon wind" theory of the late Dr. F. J. W. Whipple³ who, from observations of the anomalous propagation of the sound of explosions and from a comparison of pressure and temperature differences between England and Lapland at a height of 20 Km. (65,000 ft.), deduced that the winds at such heights are from an easterly quarter in summer and westerly in winter. Johnson⁴ reported some direct measurements of these winds by means of shell bursts at 30 Km.; these observations, which were made by Murgatroyd and Clews⁵, showed that during the summer the wind at this height in south-east England is mainly easterly, with a mean speed of 23 kt., whereas in winter there is a strong westerly component averaging about 75 kt. Table I gives a mean wind at 30 Km. of 25 kt. from a direction of 85° for the five summer ascents. In these ascents the height above which the easterly winds prevailed was about 65,000 ft., which is nearly the same as the figure of 60,000 ft. quoted by Gutenberg⁶ in a discussion of similar observations by high-altitude balloons in New Mexico and several other areas.

It will be noticed from Table I and Fig. 1 that, of the two soundings made in spring, that of March 24 showed a south-westerly wind in the upper levels, whereas the April 19 ascent indicated the summer type of wind structure. The time of change from one type to the other is consistent with Whipple's deduction that the transitions from W. wind to E. and *vice versa* occur at the end of March and in the middle of September.

All the soundings indicated a maximum of wind speed near the tropopause. In that of June 29 the maximum was very sharp, the decrease in speed above and below the peak at 40,000 ft. being about 25 kt. in 5,000 ft.; the wind direction in this case, as in all the other soundings except that on March 24, was approximately NW. The occurrence of such a sharp maximum wind speed near the tropopause suggests the existence of a "jet stream".

Temperatures up to 100,000 ft.—There have been so few direct measurements of temperature above 75,000 ft. in this country that the results of the soundings given in Table I and Fig. 1, though small in number and only representative of midsummer conditions, are of special interest. The chief feature, which they all show, is the steady rise in temperature with height in the lower stratosphere from a mean of -65°F. at 60,000 ft. to about -40°F. at 100,000 ft., *i.e.* a gradient of about $+0.6^{\circ}\text{F.}$ per 1,000 ft. ($+1^{\circ}\text{C.}$ per Km.). Practically the same mean gradient, but with the temperatures about 6°F. higher, was obtained at the same time of year in the New Mexico soundings discussed by Gutenberg⁶, who states that the agreement between the day and night data was good. On the other hand the day-time temperatures in the lower stratosphere at latitude 50° , calculated by Gowan⁷ from the effect of the absorption of radiation in the ozonosphere under radiative equilibrium conditions, are about 30°F. higher than the observed temperatures at the same levels in England. The large difference can hardly be due to the fact that the soundings were done at night since Gowan⁸ has also calculated that the cooling of the ozonosphere during a night should not amount to more than 4°F. at 100,000 ft.

The temperature-height curves for the ascents of June 29 and July 1 show well-defined single minima at about normal tropopause height. In the other soundings the curves have double minima, the lower one at the normal tropopause height of about 40,000 ft. and the other at about 55,000 ft. These features

can be interpreted as the overlapping of a multiple tropopause of the type first suggested by Bjerknes and Palmén⁹ and more recently studied by Palmén¹⁰. It has long been known that the average height of the tropopause, when traced along a meridian from equator to pole, falls steeply between latitudes 20° and 40° in winter and 35° and 50° in summer. In the process of averaging, however, discontinuities tend to disappear, but it is known that the steep change in height of the tropopause is, in fact, a discontinuity between an upper, tropic, tropopause and a lower, arctic, one. According to Hess^{11,12} the discontinuity, with some overlapping, occurs between latitudes 50° and 52° in North America in summer. It could, therefore, be expected to show up frequently in high soundings in England. Moreover, since the discontinuity is associated with the occurrence of the jet stream, some evidence of this, in the shape of the sharp maximum in wind speed near the low-level tropopause as was found in some of the soundings under discussion, could also be expected.

In the two simultaneous soundings of July 6 there was no significant difference between the temperatures at the same levels. The theoretical horizontal temperature gradient which would account for thermal winds with the speeds observed above 65,000 ft. in these ascents was computed to be 0.35°F. per 100 Km. This is about the distance north which Downham Market is from Larkhill. Such a small horizontal gradient could only be detected with the present radio-sonde over a considerably longer distance.

Future programme.—To investigate seasonal and latitude variations up to 100,000 ft. it is proposed to undertake a few high-altitude soundings each month, throughout a year, at two more widely separated stations. It is suggested that high-altitude balloons should be used, as far as possible, by Meteorological Services taking part in the special soundings on International Aerological Days.

Acknowledgements.—It will be evident that the results recorded in this note could not have been achieved but for the close co-operation of the Establishments and stations mentioned in the introduction; their assistance is gratefully acknowledged. The staffs of the radio-sonde stations at Larkhill and Downham Market, in particular, are to be commended for the care and zeal with which they undertook the specially long soundings, despite the fact that these were additional to their six-hourly routine soundings.

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12. BANNON, J. K. and GOLDIE, A. H. R.; The stratosphere. *Met. Mag., London*, 78, 1949, p. 98 (see Fig. 2, p. 102).

A NOTE ON CUMULONIMBUS PHOTOGRAPHED NEAR SINGAPORE ON MARCH 5, 1947

By J. M. CRADDOCK, M.A.

The eight photographs in Figs. 3-10 are selected from a series of 23 covering the same period, which was taken from the top of the water tower near Station Sick Quarters, Changi, Singapore Island, where the writer had spent most of the day observing cloud development. This point offers an excellent view of land and sea in all directions and a log, covering all matters of interest which were noticed, was kept during the whole period. On March 5, 1947, the visibility was very good, and during the afternoon it was evident that the cumulus cloud was occurring only over land. Until 1415 there had been no formation of cumulonimbus in any direction, but about that time the writer observed signs of the development to the south-east which forms the subject of this paper. The island of Bintan where it originated is mostly out of sight below the horizon, but the peak of Great Bintan (3,300 ft.) and the general cover of cumuliform cloud over the island are visible in the photographs. No other cumulonimbus development occurred during the day within the area of approximately 50 miles radius visible from Changi. Times in this article are given in zone time—7½ hours in advance of G.M.T.

The photographs show that, starting before 1417 a cumulonimbus rose to a great height over Bintan, and that the top was carried in an upper air stream directly towards Changi. The cloud top passed overhead at 1513. The cumuli-form part had almost dispersed by 1505, but another cumulonimbus began to form at about 1530 in what appeared to be the same place, and reached its greatest vertical development at about 1554. Its later stages, not recorded photographically, were very similar to those of the first cloud.

A pilot balloon started from Changi at 1700 was followed to 29,000 ft., the following winds being typical of the sounding

Height (ft.)	5,000	10,000	15,000	20,000	29,000
Wind (°true/kt.)	270°/18	310°/19	050°/13	090°/15	080°/21

The upper air temperatures recorded at Tengah (about 15 miles from Changi) the same morning, starting at 0730, are shown on the tephigram in Fig. 1, and Fig. 2 is a sketch map of the area.

Calculation of sizes and velocities.—When an object is photographed, the size of the image depends on the size of the object, the distance of the object from the camera, the focal length of the lens used, and the direction of the optical axis of the lens in relation to the object.

If f is the focal length of the lens, θ the angle which a given diameter of the object subtends at the camera, and x the length of the image of the diameter, then, (1) if one end of the diameter lies on the optical axis of the lens, $\tan \theta = x/f$, and (2) if the mid point of the diameter lies on the optical axis of the lens, $\tan \theta/2 = x/2f$.

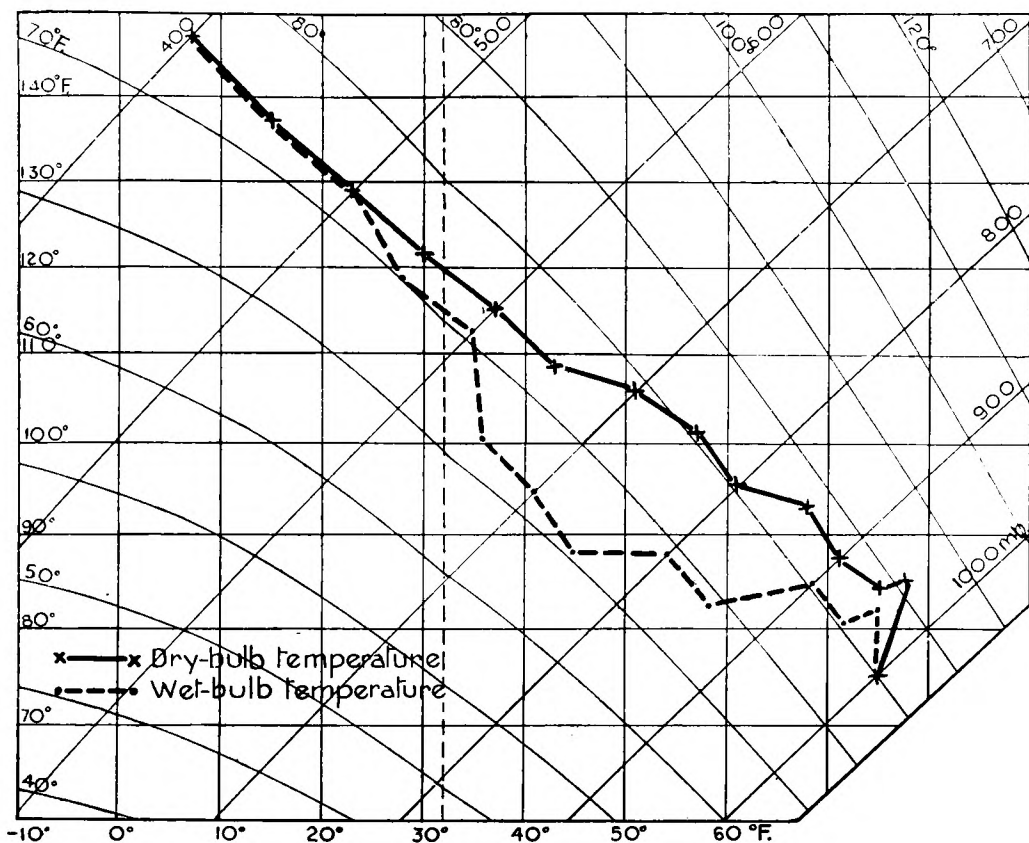


FIG. 1—UPPER AIR SOUNDING AT SINGAPORE (TENGAH) AT 0730
ON MARCH 5, 1947

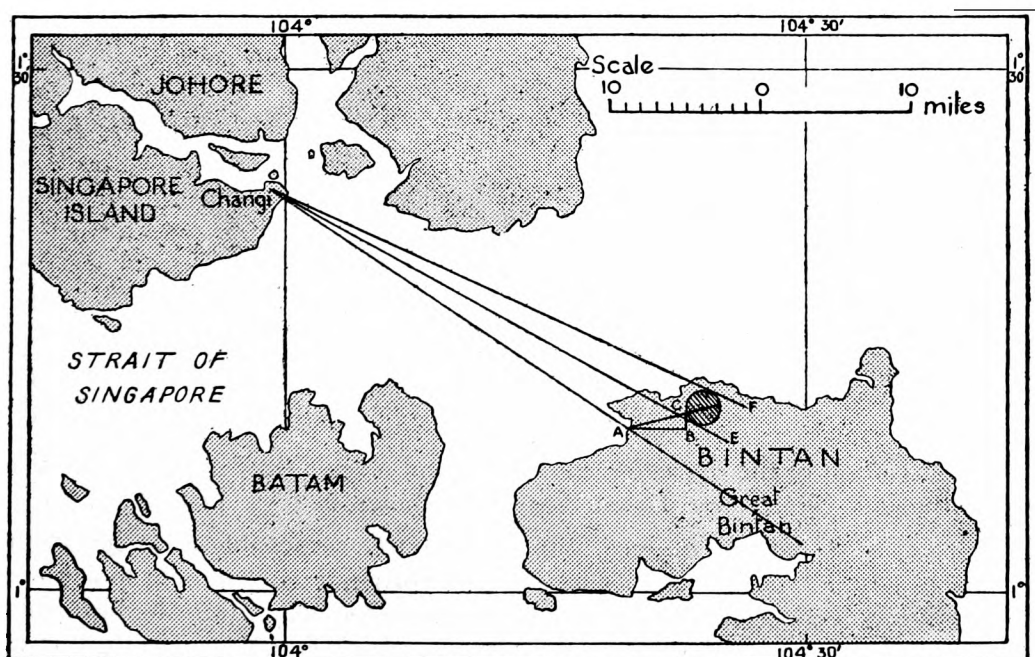


FIG. 2—MAP OF THE AREA SOUTH-EAST OF SINGAPORE

The first formula was used in finding the horizontal diameters of the clouds, the second in finding the angular elevation of the cloud tops above the visible horizon. Under the conditions of the observation it was not possible to ensure that the camera was pointed exactly towards the cloud, but the errors introduced by using the above formulæ are not considered to exceed 2 per cent. of the computed values of $\tan \theta$.

The cloud top moved towards Changi from the east-south-east, while the reported winds up to 29,000 ft. show no trace of a southerly component. It follows that the upper part of the cloud must have projected northwards over the lower, and, with the sun's elevation $7\frac{1}{2}^\circ$ south of the local vertical, have cast a shadow on it.

This shadow is first clearly visible in Fig. 4. It appears, that the cloud top started to move north-west at about 1425, and its motion between then and 1513 (when it passed overhead at Changi) is taken to be uniform.

The cloud appeared to originate over the peak of Great Bintan, the only considerable mountain on the islands south of Singapore, and to rise vertically from then until 1425. The peak is 39 miles from Changi, and this is taken to be the distance of the cloud top until 1425. The horizontal speed of the cloud top from 1425 until 1513 is thus 49 m.p.h. The second cumulonimbus is assumed to rise vertically in the same place until 1547 and the top then to move towards Changi with the same speed. On these assumptions, the vertical heights of the clouds and the horizontal diameter of the first are given in Table I.

TABLE I—SIZE AND HEIGHT OF THE TWO CLOUDS

Time	Distance from Changi	Horizontal diameter	Height	Vertical velocity
	miles	× 1,000 ft.	× 1,000 ft.	ft./min.
First cloud				
1417	39	..	23·83	
1420	39	6·80	29·55	1,907
1425	39	8·03	38·80	1,850
1430	34·9	8·85	42·97	834
1435	30·8	10·98	41·70	
1438	28·4	12·16	42·30	
1441 $\frac{1}{2}$	25·6	13·37	41·90	
1449	19·5	14·32	40·35	
1453	16·3	13·90		
Second cloud				
1524	39	..	19·8	
1530	39	..	21·0	200
1534	39	..	22·2	297
1538	39	..	23·5	320
1547	39	..	33·6	1,120
1554	33·3	..	43·2	1,375

The variation of the diameter with time, and a scale drawing of the vertical plane through Changi and Great Bintan are shown in Figs. 11 and 12.

Errors of observation.—The most important source of possible error lies in the estimate, 39 miles, of the distance at which the original development took place. The position of the apparent cloud top cannot be located within the horizontal section of the cloud, so that this measurement, which enters as a factor into all computed lengths and velocities, is subject to an error on this account of $1\frac{1}{2}$ per cent. Otherwise, the assumed distance is subject to independent



FIG. 3—CUMULONIMBUS AT 1417

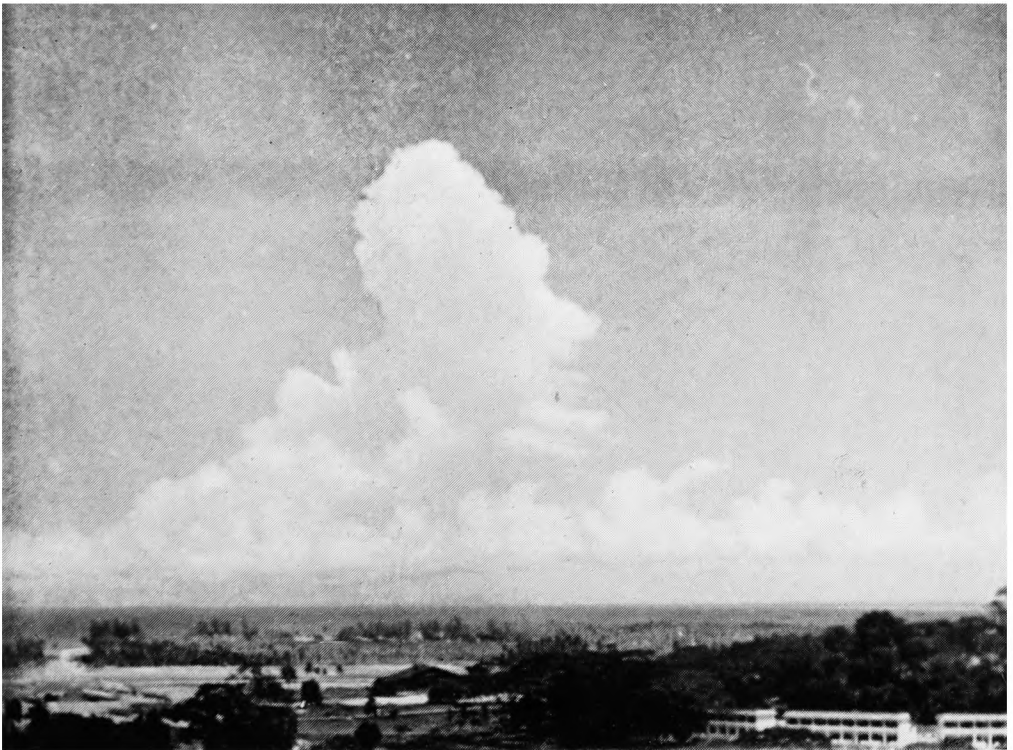


FIG. 4—CUMULONIMBUS AT 1430
CUMULONIMBUS PHOTOGRAPHED LOOKING SOUTH-EAST FROM CHANGI,
SINGAPORE ISLAND, MARCH 5, 1947



FIG. 5—CUMULONIMBUS AT 1438



FIG. 6—CUMULONIMBUS AT 1453
CUMULONIMBUS PHOTOGRAPHED LOOKING SOUTH-EAST FROM CHANGI,
SINGAPORE ISLAND, MARCH 5, 1947



FIG. 7—CUMULONIMBUS AT 1515



FIG. 8—CUMULONIMBUS AT 1527
CUMULONIMBUS PHOTOGRAPHED LOOKING SOUTH-EAST FROM CHANGI,
SINGAPORE ISLAND, MARCH 5, 1947



FIG. 9—CUMULONIMBUS AT 1538



FIG. 10—CUMULONIMBUS AT 1554
CUMULONIMBUS PHOTOGRAPHED LOOKING SOUTH-EAST FROM CHANGI,
SINGAPORE ISLAND, MARCH 5, 1947

confirmation. The peak of Great Bintan was obscured by a shower falling from the second cloud between 1538 and 1554, which precludes the possibility that the cloud rose behind the mountain. On the other hand, working on the calculated position of the cloud top at 1438, when the shadow was just crossing the edge of the small cumulus, it can be shown that the latter must lie over the area shaded on the map. The distance of the original development cannot be reduced by more than 10 per cent. consistently with the small cumulus being over land.

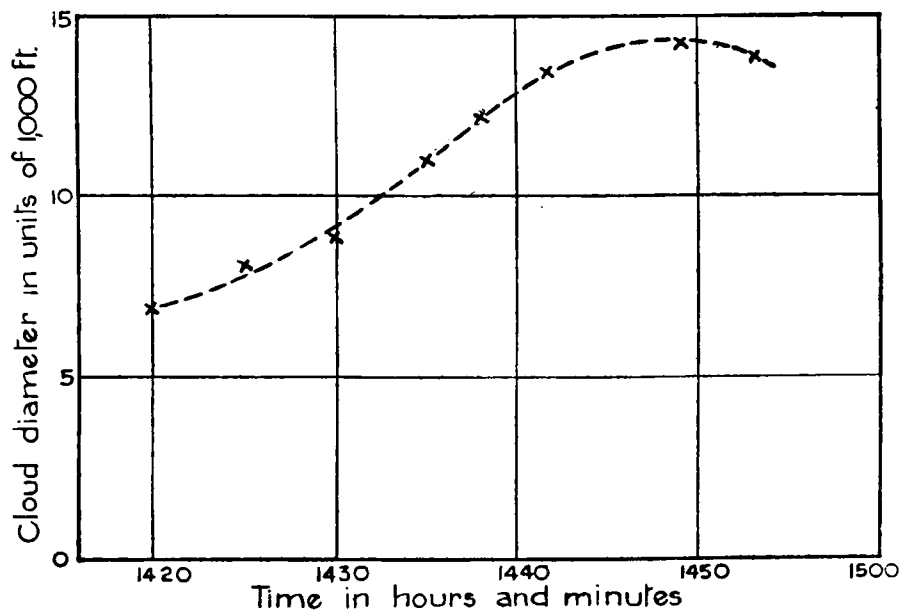


FIG. 11—CLOUD DIAMETER AT STATED TIMES

The heights are computed above the plane passing through the point of observation and tangential to the visible horizon in the direction of Bintan ; this differs from mean sea level by up to 200 ft. Also, the point of the cloud which appears highest in the photographs is not the true cloud top, but the error is considered to be small, of the order of 25-50 ft. The assumption of uniform horizontal motion cannot be checked, but the computed heights during the period of apparently horizontal motion (1430 to 1449) differ from their mean by less than 4 per cent., which suggests that the assumptions made are consistent to this degree of accuracy.

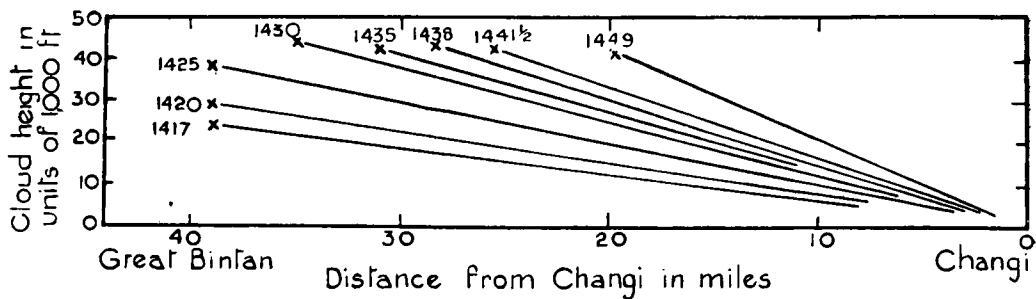


FIG. 12—DRAWING, APPROXIMATELY TO SCALE, SHOWING POSITION OF CLOUD TOP AT VARIOUS TIMES IN THE VERTICAL PLANE THROUGH GREAT BINTAN AND CHANGI

The estimates of vertical velocity, which relate to times when the clouds have little horizontal movement, are subject to a systematic error of the same order of magnitude and also to a random error of up to 6 per cent. due to an uncertainty of ± 5 sec. in the recorded times of the photographs. The estimates of cloud diameter are *prima facie* subject to the same error, though the smoothness of the curve plotted in Fig. 11 suggests that the actual error is smaller.

Mass and energy of the cumulonimbus.—The photographs show that a large bubble of saturated air broke away from its surroundings, and was dispersed at a much higher level. At 1420, when the bubble was first clearly separated, it appeared to include all the cloud above about 20,000 ft., or, say, a total weight of 150 gm./cm.² cross-section. The cross-section, assumed circular, is about 4.7×10^{10} cm.², so that the mass of the cloud is about 7.0×10^{12} gm. and its water equivalent 1.7×10^{12} gm.

The excess heat energy carried by the bubble, compared with an equal mass of the environment, follows if ΔT , the mean difference in temperature between the cloud and the environment, is known. The reported upper air sounding, when plotted on a tephigram, makes it evident that ΔT is unlikely to exceed 7°F., while a lower limit may be found by means of the following equation, due to G. I. Taylor*, for the motion of a heated bubble rising by virtue of its buoyancy :

$$v^2 = (\text{const.}) \, g d \, \Delta T / T,$$

where v is the terminal velocity of ascent, d a typical linear dimension, and T the absolute temperature of the environment. If the bubble has not reached its terminal velocity, and a is its acceleration, the equation may be written

$$a = g \, \Delta T / T - K v^2 / d$$

where K is the reciprocal of Taylor's constant and, on the analogy of a rigid sphere following O. G. Sutton, is taken to be greater than or equal to unity.

Now, assuming that the bubble moved with constant acceleration from 1417 to 1425, its velocity at 1420 was 953.8 cm./sec. and acceleration -0.125 cm./sec.². The appropriate value of T is about 259°A., so that the equation reduces to

$$\Delta T = 2.03K - 0.06$$

Thus the following values of ΔT in degrees Fahrenheit correspond to different possible values of K .

K	..	1	2	3	4
ΔT	..	2.03	4.13	6.22	8.32

Hence ΔT cannot be less than 2°F., while, since it cannot exceed about 7°F., it follows that K does not exceed 3.4.

The possible range for ΔT is thus from 2°F. to 7°F. The heat energy represented by the latent heat of condensation of the water vapour in the bubble has now to be considered. Since the cloud is saturated while the environment is not, this cannot be less than the amount by which the latent heat of condensation of air saturated at the temperature of the bubble exceeds that of air saturated at the temperature of the environment. It may, of course, be much greater. If we write $\Delta T'$ as the difference in equivalent temperatures,

*SUTTON, O. G. ; The atom bomb trial as an experiment in convection. *Weather, London*, 2, 1947, p. 105.

then this must exceed $3\cdot8^{\circ}\text{F}$. It follows that the excess heat energy of the bubble, compared with an equal mass of the environment, exceeds $3\cdot5 \times 10^{12}$ calories.

It is of interest to compare this with the figure quoted by Sutton for the energy released in the Bikini atom-bomb explosion, namely 2×10^{13} calories.

It must be emphasised that the clouds here discussed, though observed under exceptionally favourable photographic conditions, are in no way exceptional from the meteorological aspect. On the contrary, they are perfectly ordinary features of Malayan weather. The present photographic record is capable of being duplicated by any observer having a good camera.

DETERMINATION OF THE TRUE MEAN VAPOUR PRESSURE OF THE ATMOSPHERE FROM TEMPERATURE AND HYGROMETRIC DATA

By E. J. SUMNER, B.A., and G. A. TUNNELL., B.Sc.

Part II

Calculation of mean vapour pressure from the means of wet- and dry-bulb temperatures.—The partial pressure exerted by the water vapour in the atmosphere is most conveniently measured by wet- and dry-bulb thermometers enclosed in a ventilated screen. Theoretical expressions have been derived by a number of writers for the vapour pressure in terms of these two temperatures, the simplest and most generally used being due to August* (1825). The equation is of the form

$$e = a(T_1) - A[T - T_1] \quad \dots (9)$$

T_1 being the wet-bulb temperature and A a constant at a given temperature and pressure. It is the one on which the British hygrometric tables† are based; a constant pressure of 1000 mb. is assumed and A for observations in screens is empirically determined as 0.444 for T_1 above 32°F . and 0.400 for wet-bulb temperatures below freezing. There are several refinements to this formula, the commonest being

$$e = a(T_1) - B[T - T_1] \left\{ 1 + \frac{T_1 - 32}{\gamma} \right\},$$

B and γ being constants; but the additional term is very small and in the original paper it has been shown that it plays a negligibly small part in the determination of the error of the means. We shall therefore discuss equation (9) only. It should be noted that the wind velocity is not included in the equation although it is known experimentally that the wet-bulb depression is very sensitive to wind-velocity changes up to about 5 m.p.h., and insensitive above. Some account may be taken of this effect usually by giving different values to A for varying exposures, and ideally the screen should be aspirated to maintain standard flow conditions past the wet bulb. However, we are not concerned here with the inaccuracies of the formula, but with what happens in the process of averaging assuming that it gives correct results.

*AUGUST, E. F.; Über die Verdunstungskalte und deren Anwendung auf Hygrometrie. *Ann. Phys., Leipzig*, 5, 1825.

†London, Meteorological Office. Hygrometric Tables, London, 4th edition, 1940 (Reprinted 1949).

If there are n observations of T and T_1 , each of which determines a value of e in equation (9), then summing and dividing by n we get

$$\bar{e} = \frac{1}{n} \sum e = \bar{a}(T_1) - A[\bar{T} - \bar{T}_1].$$

If E_1 is the value of the vapour pressure computed from the mean wet- and dry-bulb temperatures, then

$$E_1 = a(\bar{T}_1) - A[\bar{T} - \bar{T}_1]$$

and therefore the correction, S , to be added to this value to give the true mean is given by

$$\begin{aligned} S &= \bar{e} - E_1 = \bar{a}(T_1) - a(\bar{T}_1) \\ &= \frac{a(\bar{T}_1) \sigma_{T_1}^2}{2 \bar{T}_1^4} [\alpha^2 - 2\alpha \bar{T}_1] \end{aligned} \quad \dots (10)$$

from equation (4). This expression is always positive so that the true mean vapour pressure is always higher than the computed value. The error increases steadily as the mean wet-bulb temperature rises* and is proportional to the variance of the wet-bulb data. The following conclusions based on worked examples and general experience have been drawn :—

(a) For fixed hours the correction to be added to the vapour pressure computed from monthly mean wet- and dry-bulb temperatures is generally of the order of 0.0–0.2 mb., while 0.5 mb. seems to be the extreme value. Although the error increases rapidly with wet-bulb temperature, since high wet-bulb temperatures are usually associated with small ranges of wet-bulb and *vice versa*, the greatest corrections are found in temperate regions where the greater ranges of the wet-bulb data often more than compensate for the lower temperature.

(b) For daily or monthly means the correction is of the same order as hourly means, and compares very favourably with those which arise when temperature and relative humidity means are used. It will be remembered that the biggest errors in the latter case occurred when the diurnal vapour-pressure profile showed a marked minimum at the time of maximum temperature, *i.e.* with big relative-humidity ranges, when the wet-bulb temperature would tend to remain steady and, in any case, the error is inherently smaller than previously.

(c) The annual variation of wet-bulb temperature may be almost as big as that of the dry bulb, and the required corrections are often very large for annual means. In temperate regions they may well exceed 2 mb., and sometimes double this value in polar-continental regions. To avoid such large errors it is better to compute the twelve monthly values of vapour pressure from the mean monthly wet- and dry-bulb temperatures and average them.

Other hygrometric elements.—Dew-point temperature and saturation deficit are the only other elements of sufficiently wide use to merit attention. If t is the dew-point temperature, then the vapour-pressure (e) is, by definition, equal to $a(t)$ the saturation vapour pressure at the dew-point. Therefore

$$\bar{e} = \bar{a}(t) = a(\bar{t}) \left\{ 1 + \frac{\sigma_t^2}{2\bar{t}^4} [\alpha^2 - 2\alpha \bar{t}] \right\} \quad \dots (11)$$

*It can easily be shewn that the function $a(\theta) \cdot [\alpha^2 - 2\alpha\theta]/2\theta^4$ always increases with θ .

from equation (4). Thus the problem of finding the true mean vapour pressure is reduced to that of finding the standard deviation of the distribution of dew-point temperatures.

Saturation deficit, defined as the difference between the saturation vapour pressure and the actual vapour pressure of the atmosphere, is a term most frequently used in agricultural climatology. It is just as good an indicator of the "dryness" of the air as relative humidity, but what particularly commends its use, from our point of view, is the fact that the true mean vapour pressure can be calculated from the mean temperature and the mean deficit without knowing the standard deviation of the latter. For if q is the saturation deficit, then $q = a(T) - e$ and taking means of both sides.

$$\bar{q} = \bar{a}(T) - \bar{e} \quad \dots (12)$$

The above statement follows immediately from this equation; $\bar{a}(T)$ can be calculated in the usual way from the temperature data.

The rest of this article will be devoted to ways and means of computing the required corrections in certain cases.

Calculation of the errors.—All the equations we have deduced contain averages of the climatic elements concerned and also their standard deviations. Unless we can calculate these standard deviations from the published information the true mean vapour pressure is not accurately determinable, or if, as is sometimes the case, we have at our disposal all the hourly values the labour of converting each pair of values to the vapour pressure and averaging may be prohibitive, and calculating the standard deviations by the rules given below may be quicker and sufficiently accurate to warrant their application.

The function* $\theta_T = \frac{a(\bar{T})\sigma_T^2}{2\bar{T}^4} [\alpha^2 - 2\alpha\bar{T}]$

occurs in all our equations and $\alpha a(\bar{T})\sigma_T / \bar{T}^2$ (i.e. σ_a) in one of them. To facilitate rapid calculation they have both been plotted graphically (see Fig. 1), so that given σ_T and $\bar{T}$, their values can be read off directly. For a particular mean temperature σ_a is proportional to σ_T , so that for values intermediate to those represented by dotted lines on the graph we may interpolate linearly in a vertical direction. This cannot be done with the function θ_T , but the lines are drawn sufficiently close together for one to get an accurate value without much trouble. The problem is how to find the σ 's, and the methods employed depend on the type of frequency distribution.

Consider first of all monthly tables of dry-bulb temperature and relative-humidity data. Here equation (7) is the one to use. If monthly mean values at each hour are available, to obtain the required standard deviations divide the mean daily ranges by $\sqrt{8}$. This is tantamount to assuming that temperature and humidity follow a simple sine curve in their diurnal cycle, and this procedure has been found to give remarkably accurate results, usually within 5 per cent. For convenience, a scale has been set up on the right of Fig. 1, so that, given the mean diurnal range of temperature one can read off the values of σ_a and θ_T for use in (7) without doing the preliminary calculation of σ_T . This scale can also be used to find σ_b from the mean diurnal range of relative humidity by reading across from one scale to the other. Whenever it is obvious on

* T here and in Fig. 1 refers to the dry-bulb, wet-bulb or dew-point temperature as appropriate.

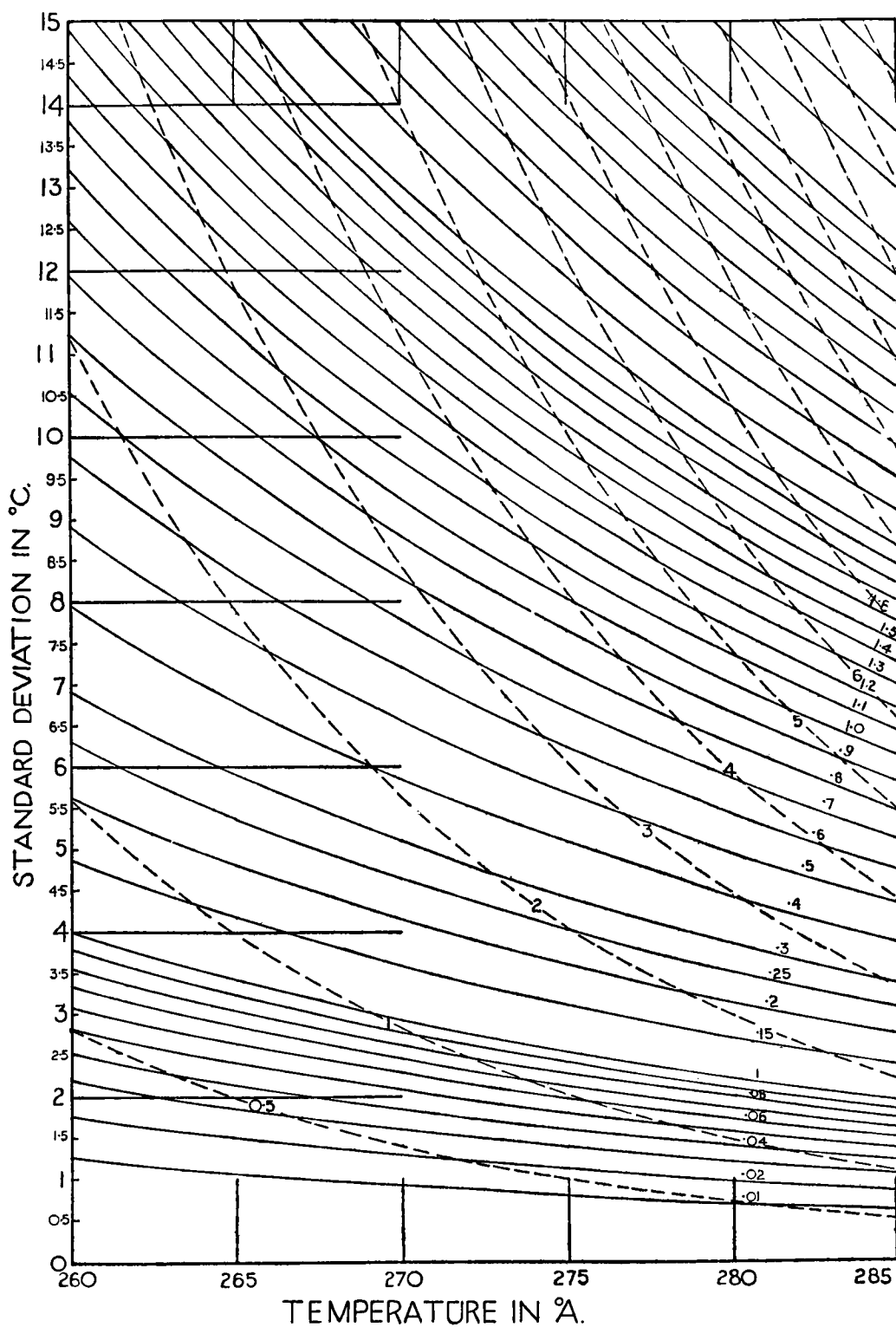
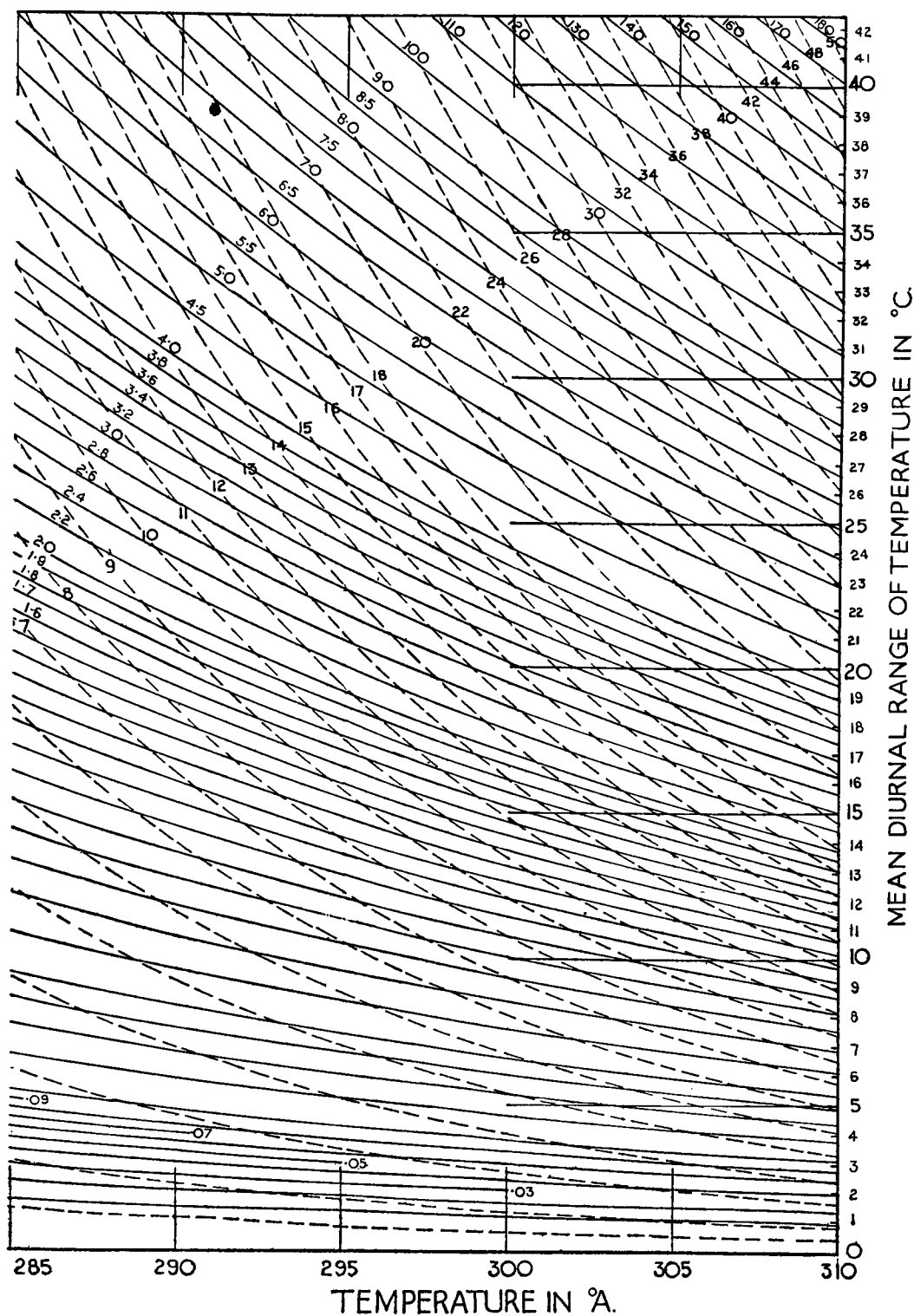


FIG. 1—DIAGRAM FOR ESTIMATING ERROR IN MEAN VAPOUR PRESSURE (mb.)

The correction to be added to the saturation vapour pressure at the mean temperature in order. The standard deviation of the saturation vapour pressure is given by the set of dotted lines.



WHEN CALCULATED FROM AVERAGES OF OTHER HYGROMETRIC ELEMENTS
 to determine the mean saturation vapour pressure is represented by the set of thick continuous lines.

inspection or reasonable to assume that the data (whatever it is) is distributed more or less cyclically this device may be used. If the range of relative humidity is not available, most stations give at least two or three observations a day and these suffice to find the amplitude of the relative humidity assuming that the diurnal variation can be represented by a single harmonic term. Frequently the range of temperature is given by M and m , the monthly mean maximum and minimum temperatures. In this case, σ_T has been found to be equal to $\{\frac{1}{3}(M-m)-\frac{1}{2}\}^{\circ}\text{C.}$ within 5—10 per cent.

In many cases the data is distributed in a haphazard sort of way. For example, suppose we have all the daily values of wet-bulb temperatures at a given hour for a particular month over several years. It is obviously impractical to work out each corresponding value of the vapour pressure and get the true mean that way. Fortunately one can get a very good estimate of the standard deviation of a random set of data consisting of 28—31 observations (*i.e.* a month) by dividing the difference between the greatest and least values by 4.3. The correlation of the monthly range of wet-bulb temperature divided by 4.3 against its actual standard deviation has been found to be 0.94, and similar accuracy is to be expected for dry-bulb and dew-point temperatures. In this way, we may quickly work out the corrections for each month in turn by equation (10) using Fig. 1, and average the true mean vapour pressures obtained over the period of years in question.

Finally, equation (10) cannot be used when the wet-bulb data includes readings both above and below 32°F. since the constant A is subject to a discontinuity at this temperature, and for averaging the data must be separated into two classes. Similarly equation (7) should only be used for relative-humidity data with respect to water or supercooled water. The practice of giving relative humidities with respect to ice below freezing point makes the data unhomogeneous and difficult to deal with.

Resumé and conclusion.—The thermal and hygrometric state of the atmosphere may be specified by many different parameters, and for a single occasion it is of little importance which combination of variables is adopted since one set can be readily converted into another by virtue of the relations which exist between them. However, as we have seen, when mean values are involved this conversion becomes more difficult. It is therefore advisable to deal only with those elements which are of most direct use and which are relatively independent. Dry-bulb temperature is, of course, the universally accepted element specifying the thermal state of the air, but no such agreement exists with respect to moisture content.

The two entities dry-bulb temperature and vapour pressure are related by the general energy balance of the atmosphere, but the relationship is so complex and so ephemeral that we may conveniently consider them as independent variables. On the other hand relative humidity is a non-linear function of both temperature and vapour pressure, and, by itself, gives no indication of the absolute amount of moisture in the atmosphere. Moreover, it does not enter explicitly into hygrometric and thermodynamical equations whereas vapour pressure does, which is an equally cogent reason for using the latter. Wet-bulb temperature, saturation deficit, and dew-point temperature are also subject to similar criticisms, and it is evident that dry-bulb temperature and vapour pressure have greater claim to figure in climatic tables. If the other

elements must be used their standard deviations or at least their range should be published as well. If a climatic table does not contain this information (and, except possibly for temperature, this is all too often the case) then no amount of ingenuity will enable one to calculate the true mean vapour pressure correctly, and it is obvious that such a table is incomplete.

The equations we have derived, although of interest in themselves, perhaps anticipate the day when standard deviations as well as arithmetic means are part of the stock-in-trade of the professional climatologist, and when meteorology is a much more exact science than it is today.

In drawing mean-vapour-pressure maps many other sources of error have to be taken into account, instrumental and errors of reduction to a standard height being the largest, and it may be considered academic to attempt to compute errors of 0.5 mb., say, when the hygrometer in use is possibly not accurate to this degree. However, the authors are of the opinion that if several errors enter into the determination of a particular value it is always something gained to eliminate or reduce one of them.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

Annual Report of the Director of the Meteorological Office presented by the Meteorological Committee to the Secretary of State for Air for the year April 1, 1948 to March 31, 1949.

This report contains an account of the work of the Meteorological Office which, as the State meteorological service, is responsible for meeting the needs of the public, the Royal Air Force, the Merchant Navy, Civil Aviation and Government Departments generally.

Among important developments during the past year may be mentioned the work of the Forecasting Research Division at Dunstable. This Research Division works at the headquarters of the forecasting service, and has at its disposal meteorological information covering the entire northern hemisphere, collected with the maximum possible speed under an internationally operated scheme. Highly complex dynamical investigations are in progress with the object of strengthening the scientific foundation of forecasting technique. Special studies are also made of occasions when weather developments have not been in accordance with anticipations.

The international scheme for maintaining weather ships in the North Atlantic Ocean made further progress, the number of such stations in operation in March 1949 increasing to 11. These include the two stations maintained by the United Kingdom some 500 miles westward of the British Isles, and a third station maintained jointly by Norway, Sweden and the United Kingdom midway between Norway and Iceland.

The air-lift operations to Berlin necessitated considerable expansion of the meteorological services provided for the Royal Air Force in Germany. Development has also taken place in connexion with civil aviation, the most important feature being the establishment of the new Air Traffic Control Centre at Preston, Lancashire. The demands for meteorological advice at London Airport show a continued increase, not only in respect of the number of aircraft operating, but also in regard to the nature of the information required. In this connexion, special attention is being paid to the accurate measurement of visibility at night, as affecting the safety of aircraft landing in unfavourable weather.

Research has been pursued in problems of atmospheric physics which have practical application to the safety of aircraft. Increasing attention is being given to the meteorological needs of agriculture. Much effort was also devoted to the development of meteorological instruments. Records of terrestrial magnetism, seismic movements, and atmospheric electricity have been maintained at the Observatories.

Representatives of the Meteorological Office took part in a number of international conferences which were held in London, Paris, De Bilt, Geneva, Oslo, Delhi, Seattle and Buenos Aires.

The Meteorological Reserve was re-formed as part of the reconstituted Royal Air Force Volunteer Reserve.

ROYAL METEOROLOGICAL SOCIETY

The annual summer outing of Fellows of the Royal Meteorological Society and their friends took the form this year of a visit on July 13 to the Royal Aircraft Establishment at Farnborough, Hampshire.

The party were welcomed by the Director, Mr. W. G. Perry, who described the general functions of the Establishment as concerned with research and development into all aspects of aeronautics, from the strength of the materials used in making aeroplanes to the gustiness of the upper atmosphere.

The programme before lunch consisted of a demonstration, with a sandbag, of the ejector seat used for escape from very fast aircraft, and of the methods used in the Strength of Materials and Aircraft Structures Laboratories. In the Structures Laboratory complete aircraft wings and other parts are tested to destruction to see whether and by how much they can withstand the greatest load likely to be imposed in flight, taking into account atmospheric turbulence and other factors.

After an excellent lunch in the R.A.E. canteen the party were in good form for the high-light of the day, the description of the work of the Meteorological Research Flight by Dr. Frith and his colleagues.

Much of this work was recently described by Dr. Frith himself in the *Meteorological Magazine**, so reference in any detail is needed in this account to newer work only. Mr. Goody explained the work being carried out by the Meteorological Office and Cambridge University on the variation of the intensity of solar radiation with wave-length at high altitudes using a high-speed thermistor bolometer. The instrument scans the energy distribution over a range of $1\ \mu$ in 7 sec. The range of $1\ \mu$ may be preselected to be anywhere within a wide band. Diagrams of the variation measured at 30,000 ft. in the region of the water-vapour absorption band at $6.3\ \mu$ were shown from which the mass of water vapour in higher layers of the atmosphere can be calculated. A demonstration with an artificial "sun" of an electronic heliostat devised to keep the sun's rays on the slit of the spectroscope used in this work aroused much interest. The heliostat not only keeps the sun shining on the slit but "finds" the sun beforehand. Mr. Shellard showed the technique due to Dessens of capturing dust particles and condensation nuclei on fine fibres. By projection on a small screen, nuclei were shown growing to spherical droplets as relative humidity was increased to room level and decreasing to small crystals as the air stream across the particles was dried.

*FRITH, R. ; Meteorological Research Flight. *Met. Mag.*, London, 77, 1949, p. 241.

Dr. Frith explained the well-known Dobson-Brewer frost-point hygrometer and three instruments intended to measure water content and drop size in clouds. Two of these are based upon the principle that the amount of water caught by a cylindrical rod projecting from the aircraft depends on the diameter of the rod and the size of the droplets because a thin rod disturbs the air stream relatively little and catches most drops in its path, and a thick one disturbs the flow so much that the smaller drops are carried round and only the larger ones go on to hit the cylinder. In one application heat is supplied to such a rod at a known rate and the amount of water caught by it can be calculated from the temperature of the rod and some other factors. By using four such cylinders a measure of the distribution of drop size is obtained. In the other application used in ice-forming clouds the cylinders are steadily rotated and the amount of ice caught on each is measured. The third instrument used the magnesium oxide slide as described in Dr. Frith's article. Mr. Grant demonstrated a very responsive thermometer being developed for use in aircraft which under low ventilation has a lag coefficient of only a fiftieth of a second and an even smaller one in aircraft use.

From the Meteorological Research Flight the party were conducted over the station Meteorological Office, the Flying Control Office with its elaborate radar apparatus, and were shown a number of modern aircraft. Tea in the canteen concluded the day's proceedings.

NOTES AND NEWS

International Meteorological Organization postage cancellation design

We are indebted to Dr. G. Swoboda, Chief of the Secretariat of the I.M.O., for permission to reproduce in the Magazine the design now used, with the standard Swiss post office place and date stamp, in the postage cancellation machine at the I.M.O. Secretariat. The device thus appears on all envelopes coming from the I.M.O.



Readers will recognise immediately the symbols and the familiar shapes on the outer curve of the design.

The Bishop Shield

In this age of excessive specialization it has become increasingly difficult to achieve success in two fields at the same time. It is accordingly a matter for special gratification when the Meteorological Office carries off the Bishop Shield against the competition of the rest of the Air Ministry and the Ministry of Civil Aviation, as it did at the Sports Meeting on August 31, 1949. To win the shield it is necessary to excel in games like football and cricket as well as in athletics and swimming, and it is this overall quality which endows the holding of the shield with such value.

While chief credit must, of course, go to the individual performers of both sexes, a measure of the success of the Office as a whole must be attributed to the enthusiasm of the energetic members of our Sports Committee. In view of the fine team spirit that has been shown, it might be considered invidious to refer to individuals, but it would be less than fair to omit mentioning the achievements of Mr. A. F. Lewis as a swimmer and of Mr. W. Lawson as a medium-distance runner. A special word of praise is due to the ladies, amongst whose efforts the graceful high jumping of Miss Pope and Miss Gilpin earned the applause of the spectators at the Polytechnic Stadium. We must also not forget the indefatigable Secretary of our Committee, Mr. H. A. Scotney, the work done by Mr. P. M. Shaw in rallying the staff at Harrow, and the similar task performed by Mr. R. M. Rudlin at Dunstable.

To all who have contributed in any way towards the winning of the Bishop Shield I offer the warmest congratulations of their colleagues in the Meteorological Office. Is it too much to hope that next year we may place beside it the Simpson Cup, and thus honour the former Director whose name it commemorates?

N. K. JOHNSON

NEWS IN BRIEF

The Council of the Physical Society has awarded the Charles Chree Medal and Prize for 1949 to Dr. G. M. B. Dobson, F.R.S., for his work on physical meteorology, especially on the physics of the upper air.

REVIEW

Atmospheric Electricity. By J. Alan Chalmers. 8vo. 9 in. $\times$ 5½ in. viii + 176. Geoffrey Cumberlege, Oxford, Clarendon Press, 1949. Price: 15s. *od.*

Atmospheric electricity is usually regarded as forming a well defined section of geophysics but its connexion with meteorology is naturally very close. In such aspects as the conduction of electricity in the air it can be treated under the heading of pure physics, whilst there are certain applications of atmospheric electricity, such as lightning protection, which are more appropriate to the realm of applied physics. One finds, therefore, that published work on the subject is scattered through a wide variety of scientific journals, and, as in many other subjects, it is no easy task to keep track of research that is going on in various parts of the world. For some years now there has been a need for one of the active workers on atmospheric electricity to collect together the main results, particularly of recent work, in book form. Dr. Chalmers, who is well known for his own researches on the subject, has undertaken this task and the book he has written is one which, despite one or two limitations, can be recommended to every student or worker on the subject.

One of the limitations is that the author does not treat his subject in a very discursive manner, and although there are advantages in having the essentials of the subject presented in concise form one cannot escape the feeling that the book is a well arranged collection of very good abstracts. The descriptive background and the critical analysis of theories and results are kept down to a bare minimum. While, therefore, the book forms a very handy and comprehensive source of reference for the student or research worker the newcomer may find it rather a dry introduction.

Another limitation is that although, according to the notice on the dust cover, the book purports to include results of the latest work which has only been available previously in scientific journals, it does not mention the work of Findeisen in Germany in 1943 and of Frenkel in the U.S.S.R. in 1944. Both these workers have put forward theories to account for the generation of electric charge in clouds, and although these theories may not be generally accepted, one would expect to find them referred to in an up-to-date account of the subject. On the other hand it is noteworthy that the very recent work of Simpson on the electricity of disturbed weather has been included.

These two criticisms, however, are minor ones, and the writer would like to emphasise his view that the book is a very welcome addition to the literature of the subject. No text-book on atmospheric electricity, in the English language, more recent than the volume published in 1939 in the "Physics of the Earth" series, was available until Dr. Chalmers' book appeared, and despite the war years and the fact that the subject has relatively few military applications, a surprising amount of work seems to have been done in the interval.

The lay-out of the book is well balanced. After a historical introduction and a summary of general principles the various aspects of the subject are dealt with in detail. These include atmospheric ionization, the earth's electric field, currents due to conduction, precipitation and point discharge, and thunderstorm electricity. Cosmic rays and earth currents, which have come to be regarded as being outside the scope of atmospheric electricity, are excluded. The book is provided with a good bibliography and author and subject indexes.

There is scarcely any need to say that the production of the book is well up to the high standard one expects from the Clarendon Press. The volume forms one of their international series of monographs on physics and the price compares very favourably with those of the other volumes in this series.

F. J. SCRASE

WEATHER OF AUGUST 1949

Mean pressure for August was 1020 mb. or above over an area extending from west of the Azores north-eastwards across the Atlantic, the Bay of Biscay, northern France and the English Channel. It decreased northwards to 1010 mb. or below in northern Norway, the Faeroes, Iceland and over the western Atlantic north of about 55°N. Mean pressure was above the average over most of the north-eastern Atlantic and western and central Europe including Scandinavia; the greatest excess, 5 mb. above the average, was over the British Isles. Pressure was generally below the average near the Azores and over the western Atlantic.

Broadly speaking, the weather over the British Isles was dry in England and Wales, Northern Ireland and south Scotland, but wet in the west and north of Scotland, particularly the north-east. It was sunny in England and Wales and south Scotland; mean temperature exceeded the average generally.

Unsettled weather prevailed for the most part during the first ten days. From the 1st to the 3rd a complex depression moved across the northern half of the British Isles to southern Scandinavia. Rain fell generally on the 1st and showers and local thunderstorms on the 2nd; rainfall was heavy in central Wales on the 1st, 2.02 in. being measured at Hafod Fawr, Merioneth. In the

rear of the depression on the 3rd, strong north-westerly winds prevailed, reaching gale force locally, and scattered showers were recorded mainly in the northern half of the country. Another deep depression, which was situated over the Atlantic westward of Scotland on the 5th, moved north-east to Thorshavn by the 8th. Meanwhile associated troughs of low pressure crossed the British Isles giving rain in the north and west. On the 7th and 8th a vigorous depression north-east of the Azores moved quickly across England to Scandinavia causing local gales on the 7th and 8th and heavy rain in some areas on the 7th. At many places in Scotland and Northern Ireland rainfall on the 7th amounted to more than 2 in.; *e.g.* 2.90 in. at Loch Vennachar, Perthshire, 2.43 in. at Kilmarnock, Ayrshire, and 2.07 in. at Annalong, Mourne Mountains. On the 9th an anticyclone situated south-westward of the British Isles moved slowly east and on the 10th a shallow secondary depression off north-west Ireland moved south-east to the southern North Sea and thence east to Germany where it filled. Rain occurred generally on the 10th. On the 11th a small anticyclone westward of Scotland moved south-east and fair weather prevailed apart from slight rain in the Hebrides and extreme north-west of Scotland. Subsequently, pressure was high in a belt extending from south-west of Ireland across southern England to Germany; meanwhile, troughs or shallow secondary depressions moved east over the northern half of the country. Fair, warm weather prevailed in England and Wales, but rain occurred at times in Scotland and Northern Ireland; temperature rose to 88°F. at Greenwich on the 15th. On the 17th an anticyclone situated west of Ireland moved south, and from the 17th to the 19th a trough of low pressure moved slowly east giving rain at times, chiefly in the western half of the country. On the 20th and 21st an anticyclone over the British Isles moved away east-south-east to Germany; very warm weather prevailed and it was fair in England and Wales, but rain occurred in north Scotland on the 20th and local thunderstorms in Scotland and Ireland on the 21st. From the 23rd to the 27th pressure was fairly uniform over the British Isles, and, apart from scattered rain or thunderstorms, mainly fair weather prevailed, though there was considerable mist or fog. From the 28th to the 30th a complex Atlantic depression moved north-east across Iceland while a trough crossed the British Isles. Rain fell in the west on the night of the 28th–29th and more generally, apart from south-east England, on the 29th, while scattered rain and local thunderstorms were experienced on the 30th. On the last day of the month a trough of low pressure to the west of Ireland moved east, giving rain generally and rather widespread thunderstorms.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	88	36	+2.3	63	—6	117	45
Scotland	81	33	+1.5	113	—1	97	27
Northern Ireland ..	76	42	+1.8	81	—2	87	42

RAINFALL OF AUGUST 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ..	1.25	57	<i>Glam.</i>	Cardiff, Penylan ..	2.33	55
<i>Kent</i>	Folkestone, Cherry Gdn.	.95	40	<i>Pemb.</i>	St. Ann's Head ..	2.99	90
"	Edenbridge, Falconhurst	1.63	62	<i>Card.</i>	Aberystwyth ..	2.94	77
<i>Sussex</i>	Compton, Compton Ho.	1.77	57	<i>Radnor</i>	Tyrmynydd ..	2.84	53
"	Worthing, Beach Ho.Pk.	2.11	93	<i>Mont.</i>	Lake Vyrnwy ..	3.15	61
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	1.02	51	<i>Mer.</i>	Blaenau Festiniog ..	8.21	73
"	Bournemouth ..	.86	34	<i>Carn.</i>	Llandudno ..	2.13	76
"	Sherborne St. John ..	1.75	72	<i>Angl.</i>	Llanerchymedd ..	2.94	81
<i>Herts.</i>	Royston, Therfield Rec.	1.36	53	<i>I. Man.</i>	Douglas, Borough Cem.	3.28	86
<i>Bucks.</i>	Slough, Upton ..	1.54	71	<i>Wigtown</i>	Port William, Monreith	2.55	66
<i>Oxford</i>	Oxford, Radcliffe ..	1.48	65	<i>Dumf.</i>	Dumfries, Crichton R.I.	2.53	63
<i>N'hant.</i>	Wellingboro', Swanspool	.95	40	"	Eskdalemuir Obsy. ..	3.68	71
<i>Essex</i>	Shoeburyness ..	1.16	66	<i>Roxb.</i>	Kelso, Floors ..	2.17	74
<i>Suffolk</i>	Campsea Ashe, High Ho.	.93	47	<i>Peebles</i>	Stobo Castle ..	2.69	76
"	Lowestoft Sec. School ..	.78	35	<i>Berwick</i>	Marchmont House ..	2.50	76
"	Bury St. Ed., Westley H.	1.54	59	<i>E. Loth.</i>	North Berwick Res. ..	2.21	70
<i>Norfolk</i>	Sandringham Ho. Gdns.	2.32	86	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	3.33	104
<i>Wilts.</i>	Bishops Cannings ..	1.61	52	<i>Lanark</i>	Hamilton W. W., T'nhill	3.98	116
<i>Dorset</i>	Creech Grange ..	1.09	38	<i>Ayr</i>	Colmonell, Knockdolian	3.40	85
"	Beaminster, East St. ..	1.83	58	"	Glen Afton, Ayr San ..	3.66	68
<i>Devon</i>	Teignmouth, Den Gdns.	1.10	49	<i>Bute</i>	Rothsay, Ardenraig ..	5.38	110
"	Cullompton ..	2.35	77	<i>Argyll</i>	L. Sunart, Glenborrodale	8.82	155
"	Barnstaple, N. Dev. Ath.	1.93	58	"	Poltalloch ..	4.97	101
"	Okehampton, Uplands	3.36	79	"	Inveraray Castle ..	7.17	109
<i>Cornwall</i>	Bude, School House ..	1.63	58	"	Islay, Eallabus ..	5.43	125
"	Penzance, Morrab Gdns.	1.68	53	"	Tiree ..	3.87	92
"	St. Austell, Trevarna ..	1.71	47	<i>Kinross</i>	Loch Leven Sluice ..	3.62	95
"	Scilly, Tresco Abbey ..	1.72	63	<i>Fife</i>	Leuchars Airfield ..	3.02	98
<i>Glos.</i>	Cirencester ..	1.50	50	<i>Perth</i>	Loch Dhu ..	6.53	97
<i>Salop.</i>	Church Stretton ..	1.87	56	"	Crieff, Strathearn Hyd.	3.32	79
"	Cheswardine Hall ..	1.70	51	<i>Perth</i>	Pitlochry, Fincastle ..	2.90	82
<i>Worcs.</i>	Malvern, Free Library	1.27	44	<i>Angus</i>	Montrose, Sunnyside ..	4.08	146
<i>Warwick</i>	Birmingham, Edgbaston	2.11	78	<i>Aberd.</i>	Braemar ..	3.06	90
<i>Leics.</i>	Thornton Reservoir ..	1.79	64	"	Dyce, Craibstone ..	4.63	153
<i>Lincs.</i>	Boston, Skirbeck ..	2.02	85	"	Fyvie Castle ..	5.64	177
"	Skegness, Marine Gdns.	2.35	96	<i>Moray</i>	Gordon Castle ..	6.39	202
<i>Notts.</i>	Mansfield, Carr Bank ..	1.90	68	<i>Nairn</i>	Nairn, Achareidh ..	4.51	186
<i>Derby</i>	Buxton, Terrace Slopes	2.77	63	<i>Inv's</i>	Loch Ness, Foyers ..	..	..
<i>Ches.</i>	Bidston Observatory ..	1.72	56	"	Glenquoich ..	11.10	135
<i>Lancs.</i>	Manchester, Whit. Park	2.68	78	"	Fort William, Teviot ..	9.08	146
"	Stonyhurst College ..	3.74	74	"	Skye, Duntuilum ..	6.58	148
"	Blackpool ..	2.65	74	<i>R. & C.</i>	Ullapool ..	3.87	113
<i>Yorks.</i>	Wakefield, Clarence Pk.	1.97	76	"	Applecross Gardens ..	8.04	170
"	Hull, Pearson Park ..	1.70	58	"	Achnashellach ..	8.24	131
"	Felixkirk, Mt. St. John	2.43	85	"	Stornoway Airfield ..	3.22	85
"	York Museum ..	1.76	70	<i>Suth.</i>	Laig ..	..	..
"	Scarborough ..	1.72	62	"	Loch More, Achfary ..	8.31	142
"	Middlesbrough ..	1.98	72	<i>Caith.</i>	Wick Airfield ..	3.94	143
"	Baldersdale, Hury Res.	1.63	47	<i>Shetland</i>	Lerwick Observatory ..	2.58	86
<i>Norl'd.</i>	Newcastle, Leazes Pk. ..	2.03	72	<i>Ferm.</i>	Crom Castle ..	2.75	66
"	Bellingham, High Green	2.80	79	<i>Armagh</i>	Armagh Observatory ..	3.03	84
"	Lilburn Tower Gdns. ..	1.93	68	<i>Down</i>	Seaforde ..	3.94	105
<i>Cumb.</i>	Geltsdale ..	2.17	53	<i>Antrim</i>	Aldergrove Airfield ..	2.70	75
"	Keswick, High Hill ..	3.13	60	"	Ballymena, Harryville ..	2.93	69
"	Ravenglass, The Grove	3.83	84	<i>L'derry</i>	Gargagh, Moneydig ..	3.00	77
<i>Mon.</i>	Abergavenny, Larchfield	1.46	49	"	Londonderry, Creggan	3.76	81
<i>Glam.</i>	Ystalyfera, Wern House	4.90	79	<i>Tyrone</i>	Omagh, Edenfel ..	2.91	68

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, APRIL 1949

STATIONS	PRESSURE		TEMPERATURES					REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE		
	Mean of day M.S.L.	Diff. from normal	Mean values				Total			Diff. from normal	Days	Daily mean	Per- centage of possible	
			Mean values											
			Max.	Min.	Max. 1 and 2 Min.	Diff. from normal								Wet bulb
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	oktas	in.	in.	hr.	%	
London, Kew Observatory	mb.	mb.	78	32	51.8	+4.1	47.1	68	5.0	1.46	+0.01	12	7.0	51
Gibraltar	1017.8	+3.7	82	51	63.5	+2.6	58.9	76	4.8	2.54	—	9	6.8	52
Malta	1019.9	1.6.5	76	45	60.8	-0.1	58.0	67	2.9	0.16	—	2	10.2	78
St. Helena	1015.0	-0.4	76	60	63.2	+3.0	63.5	98	7.5	4.28	+0.81	21	—	—
Lungi, Sierra Leone	1011.4	—	98	72	82.2	—	75.7	78	4.7	2.38	—	6	7.6	63
Lagos, Nigeria ..	1006.2	-3.2	95	70	83.0	+0.2	79.1	78	6.6	2.88	—	6	6.7	55
Kaduna, Nigeria ..	1007.5	—	100	62	83.4	+1.2	72.7	59	5.2	1.76	-1.32	2	7.8	63
Chileka, Nyasaland	1016.8	+0.3	88	58	72.1	+0.3	65.1	72	3.7	0.81	-0.59	10	7.0	60
Lusaka, Rhodesia ..	1014.7	+0.5	87	54	58.7	+1.6	62.3	73	2.1	0.86	+0.10	1	9.9	85
Salisbury, Rhodesia	1016.7	+0.2	83	46	66.5	+0.6	58.0	67	1.9	0.46	-0.61	3	8.5	73
Cape Town.. ..	1017.8	+1.4	85	49	63.5	+0.3	54.3	76	4.3	2.49	+0.62	13	—	—
Palmietfontein, S. Africa	1019.9	—	80	33	61.1	—	50.5	66	1.0	1.22	—	4	9.6	—
Mauritius	1006.8	+0.4	96	68	83.7	-1.9	77.3	74	4.6	6.00	+3.82	11	8.7	69
Calcutta, Alipore Obsy	1008.9	+0.1	94	73	84.1	+1.0	76.5	71	1.7	0.00	-0.05	0	9.6	76
Bombay	1008.2	-0.2	108	77	88.1	+2.8	78.1	69	4.6	0.91	+0.28	3	9.9	80
Madras	1009.8	+1.1	90	71	80.9	-1.8	76.3	84	4.7	22.98	+13.25	14	7.6	62
Colombo, Ceylon ..	1009.8	+0.9	94	73	81.9	+0.3	76.8	83	6.1	9.47	+1.84	19	—	—
Singapore	1014.6	+2.0	87	59	66.8	+0.5	67.2	83	—	5.21	-0.44	12	4.1	32
Hongkong	1022.6	+4.2	87	49	62.3	-2.4	57.1	75	4.1	1.24	-4.28	12	6.3	56
Sydney, N.S.W. ..	1022.5	+3.0	81	38	56.5	-3.0	51.4	74	6.0	1.19	-0.98	12	4.7	42
Melbourne	1023.4	+3.6	85	45	62.3	-1.6	—	—	3.0	0.22	-1.50	9	6.7	60
Adelaide	1017.5	-0.9	96	49	61.2	+3.3	61.2	54	4.1	1.91	+0.26	11	6.5	58
Perth, W. Australia	1019.3	+1.0	93	41	66.5	+1.5	54.0	41	2.8	0.00	-0.96	0	—	—
Coalgardie	1020.4	+2.8	88	52	67.7	-2.6	61.1	67	3.6	0.63	-3.14	7	7.4	64
Brisbane	1019.0	+4.2	74	35	52.5	-2.7	46.3	65	5.0	1.06	-0.79	8	6.1	56
Hobart, Tasmania ..	1011.3	-5.8	68	40	53.5	-2.3	50.6	80	5.1	4.85	+0.97	16	5.5	50
Wellington, N.Z. ..	1011.0	+0.4	89	68	73.2	+0.2	76.2	88	6.2	25.00	+12.88	22	4.8	41
Suva, Fiji	1010.8	+1.1	89	72	81.7	+1.5	78.8	79	4.7	7.00	-2.77	23	8.5	72
Apia, Samoa	1014.8	+0.7	94	67	80.1	+1.7	73.0	67	2.0	0.21	-1.03	3	9.7	78
Kingston, Jamaica..	—	—	91	70	80.0	+1.1	74.0	74	4.0	1.26	-0.90	12	—	—
Grenada, W. Indies	1014.4	-1.7	75	28	45.9	+3.8	36.0	66	5.3	1.15	-1.14	9	6.4	48
Toronto	1014.4	-2.3	88	15	42.7	+5.0	32.2	80	0.8	0.08	-1.32	4	7.4	54
Winnipeg	1011.6	-1.8	58	28	42.2	+3.2	37.7	82	8.0	3.70	+0.19	15	5.2	39
St. John, N.B. ..	1018.8	+1.3	64	31	47.1	-0.8	40.2	86	6.4	1.41	-0.11	12	6.7	49
Victoria, B.C. ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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PRESSURE IRREGULARITIES ON AUGUST 23-24, 1944

By C. K. M. DOUGLAS, B.A.

Some unusual irregularities of pressure were observed on August 23-24, 1944. One of these crossed Birmingham at about 0735 G.M.T. on the 23rd and attracted attention because of its effect on gas pressures. A copy of the barograph trace at Edgbaston Observatory, kindly supplied by Mr. A. L. Kelley, is reproduced in Fig. 1a, and the anemometer trace in Fig. 2a. There was a sharp rise of pressure of $2\frac{1}{2}$ mb. accompanied by a brief squall from SSW., followed within a few minutes by a fall of pressure to its original value, and a return of the easterly wind, though there was some permanent veer and decrease.

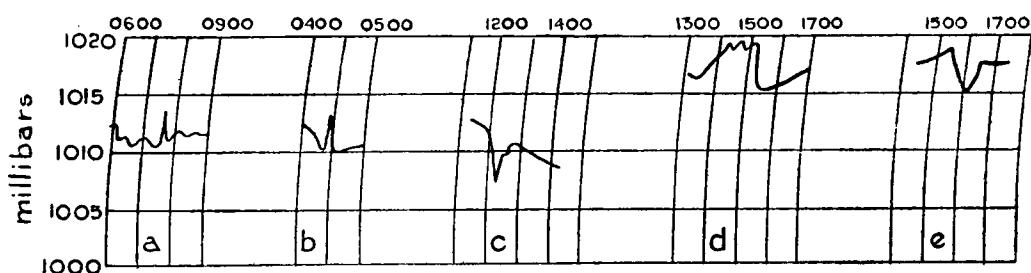


FIG. 1—BAROGRAPH TRACES, AUGUST 23-24, 1944

- a.—Edgbaston, August 23 b.—Boscombe Down, August 23
c.—Killadeas, August 23 d.—Felixstowe, August 24
e.—Dunstable, August 24

The chart for 0800, Fig. 3, shows an irregular pressure distribution with a shallow depression off our south-west coasts, which was moving north and being absorbed by a trough coming in from the west. The hourly charts showed no simple sequence. There was a layer of low stratus from the North Sea with a temperature inversion above it. The squall was associated with a cold front between 900 and 800 mb. At Larkhill the temperature at 900 mb. was 65°F . at midnight, falling to 58° at 0600 and to 53° at noon. Above the 800-mb. surface the temperature difference was eliminated by subsidence behind the front. The 0600 sounding at Larkhill, in rain behind the squall, shows deep damp air and a saturated adiabatic lapse rate. None of the soundings in the British Isles showed appreciable actual or potential instability, but there must have been some instability at the front, which gave thunderstorms and heavy

rainfall over a large area in the west. Boscombe Down had 19 mm. of rain in 9 minutes shortly before 0500 G.M.T., and the brief squall accompanying it gave a gust of 62 m.p.h. The barograph trace, Fig. 1*b*, was similar to that at Birmingham. At London and Dunstable there was only a slight shower, but the barograph showed a line-squall effect, though there was no actual squall, but only a temporary change to a light southerly wind. All over the area affected by the squall the wind returned to E. afterwards, but there was some permanent veer and decrease of wind. A further veer occurred some time later as the trough of low pressure moved north, with a wedge of high pressure spreading northward behind it. In spite of very high surface dew points this trough gave no rain. The speed of the front was about 30 kt. in the west but in the east it was somewhat less.

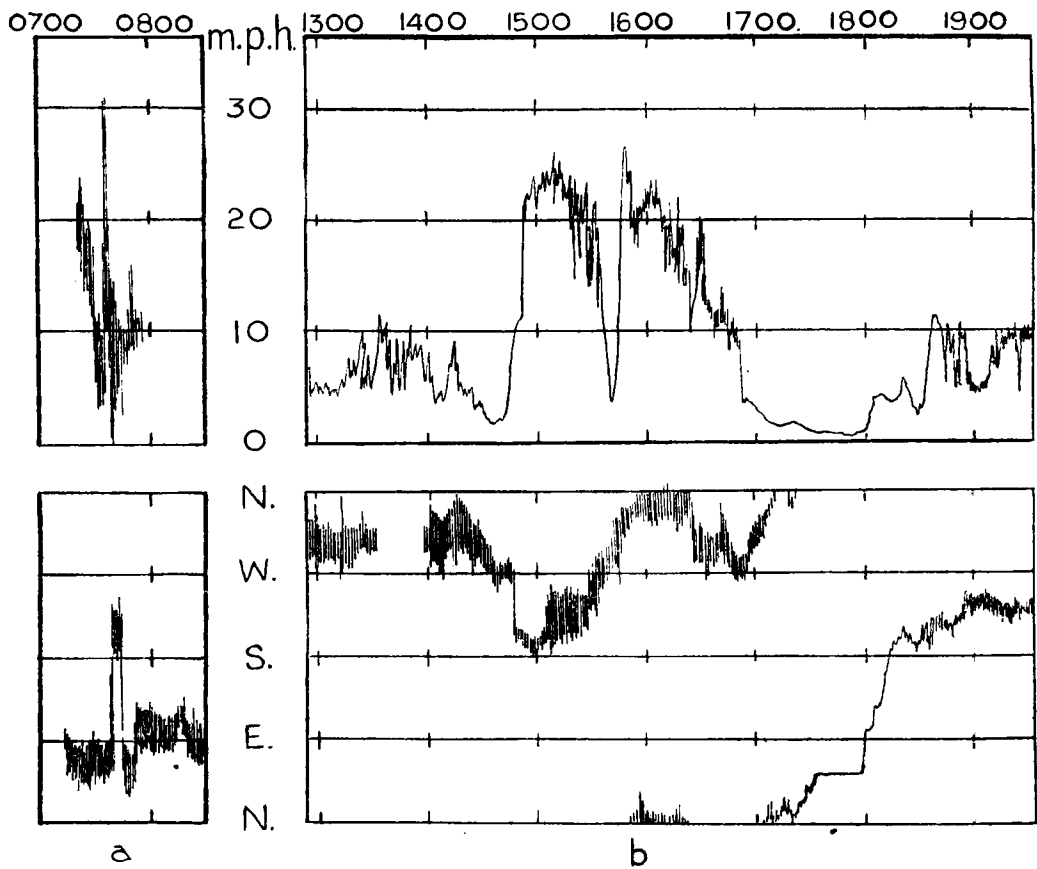


FIG. 2—WIND RECORDS, AUGUST 23-24, 1944
a.—Edgbaston, August 23 b.—Felixstowe, August 24

At 0600 the remains of a warm front extended from the southern end of Cardigan Bay to The Wash. This had a history and was still associated with a slight difference of surface temperature and dew point, but it had become poorly related to the general thermal field and was afterwards dropped. There was, however, some northward decrease of temperature at 900-800 mb. in the air ahead of the front, and Squires Gate was the most northerly station to show a line-squall effect. Rain crossed west and central Scotland with thunderstorms in places but frontal effects were weak.

The line of rain crossed Ireland, and at Killadeas (Co. Fermanagh) there was a fluctuation of pressure of the opposite kind to that observed in England. Pressure fell $4\frac{1}{2}$ mb. in about 20 min. Fig. 1c shows a copy of the barograph trace. It occurred during continuous rain, and the E. wind became temporarily rather squally.

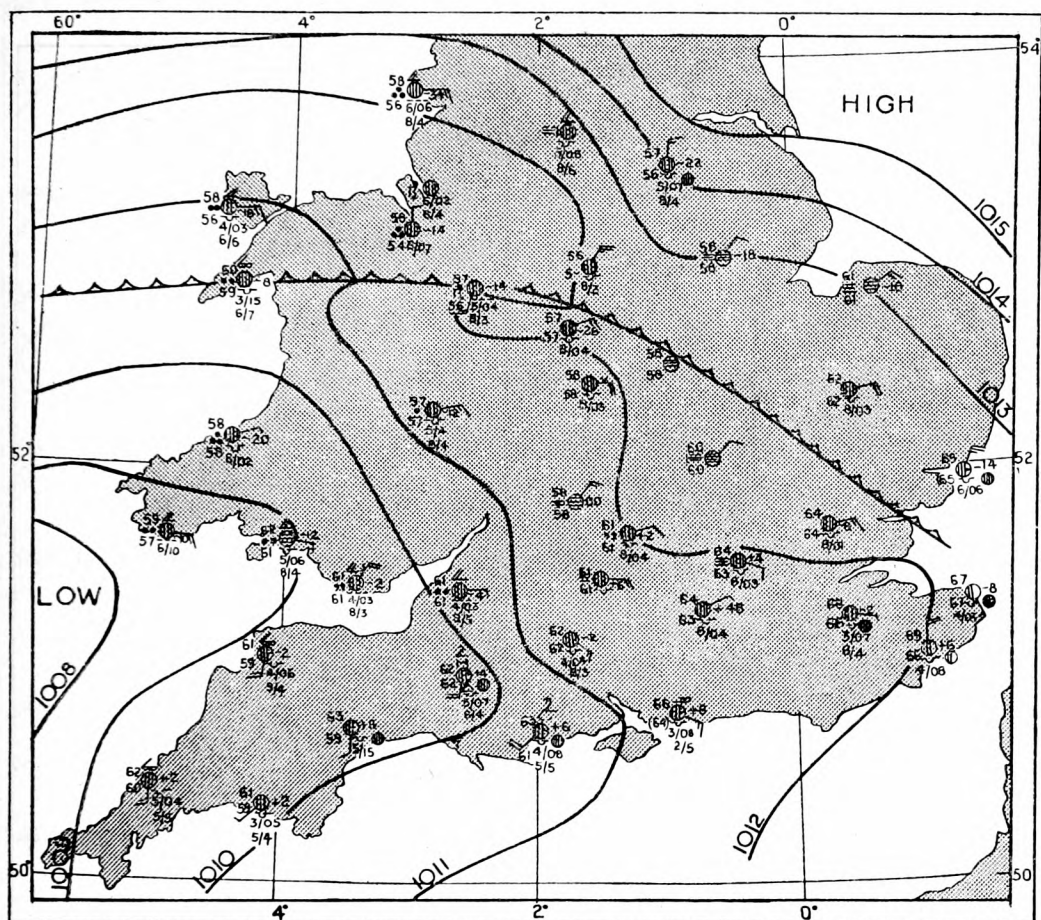


FIG. 3—SYNOPTIC CHART, AUGUST 23, 1944, 0800, SHOWING UPPER COLD FRONT

The Director of the Meteorological Service of the Irish Free State was good enough to send copies of the autographic traces from a number of places in Ireland. The trough was nowhere so pronounced as at Killadeas, but it showed at Dublin (depth 2 mb.), Baldonnell and Mullingar. At Aldergrove it only just showed and was very weak. The aircraft sounding at that station, Fig. 4a, showed that instability was on a small scale only, both in amount and in the depth of the layers affected.

Further remarkable fluctuations of pressure took place in the eastern and midland districts of England on August 24, associated with high-level thunderstorms. At Yarmouth pressure fell $4\frac{1}{2}$ mb. in half an hour at 0200. At Felixstowe most of the fall shortly after 1500, Fig. 1d, was even more abrupt, but the recovery was much slower than the fall. The wind record, Fig. 2b, shows that during the fall of pressure there was complete lack of balance between the wind and the gradient. Part of the fall may have represented development

rather than movement. The same disturbance affected a large area extending from the east Midlands to Yarmouth and from the south-east coast to Cranwell and Spurn Head. In general the fall of pressure was less abrupt than at Felixstowe, but nevertheless the trough was a notable one. There was a pronounced rise of pressure at the beginning of the rain, followed by a rapid fall to a minimum about or just before the end of the rain. Fig. 1e shows a copy of the Dunstable barogram with a fall of $4\frac{1}{2}$ mb. in half an hour. The

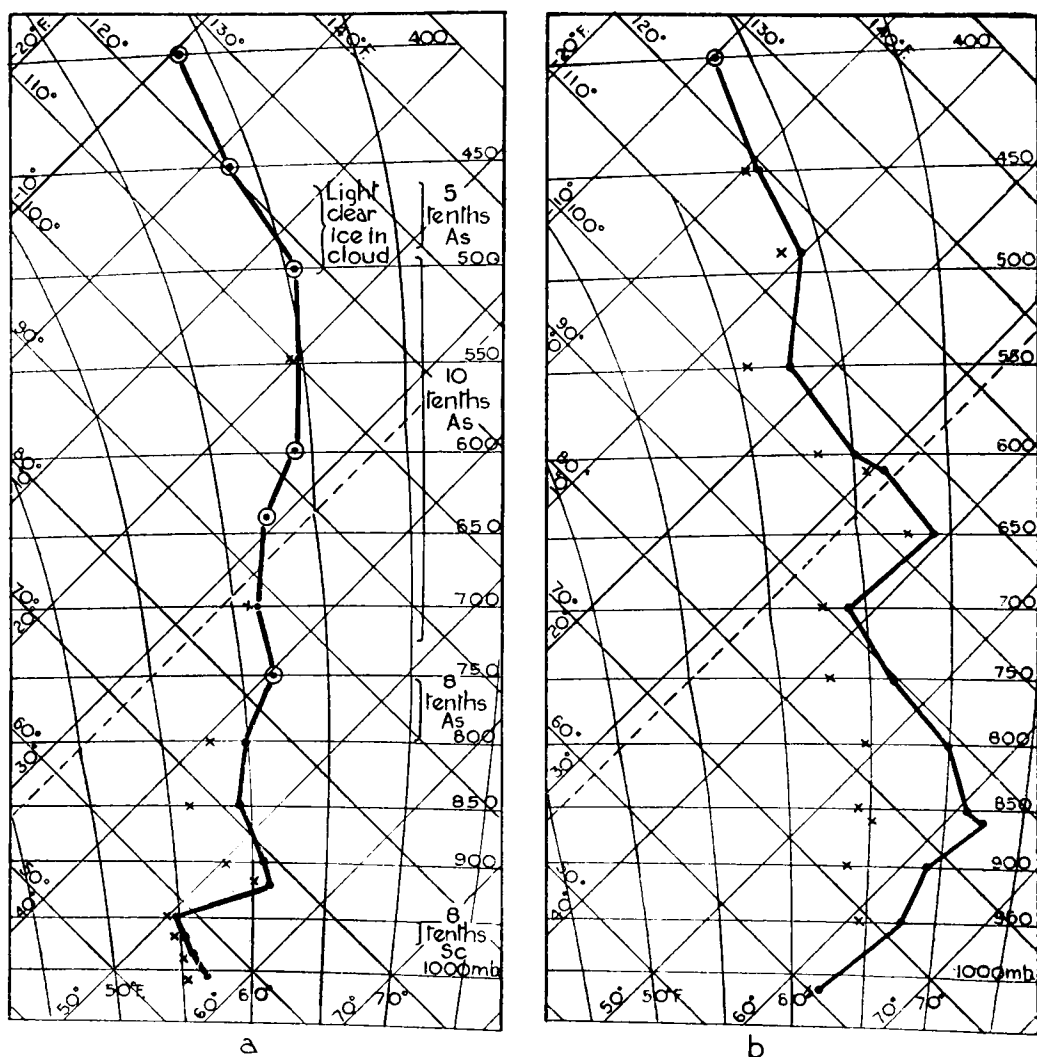


FIG. 4—TEPHIGRAMS, AUGUST 23-24, 1944
a.—Aldergrove, August 23, 1040 b.—Downham Market, August 24, 1800
Wet-bulb readings shown by crosses

trough occurred just an hour later than in London (Kingsway) giving a speed of 27 kt. This may be compared with the winds at medium levels at Downham Market and Larkhill, given in Table I. The duration of the rain ranged up to just over two hours, and taking a speed of 27 kt. this gives the rain belt a width ranging up to 65 miles. Amounts in this storm ranged up to at least 28 mm. The available information does not fit into any simple pattern, which one could hardly expect in the case of an instability phenomenon, but there is evidence of elongation across the vertical wind shear. At 1800, Fig. 5, Spurn

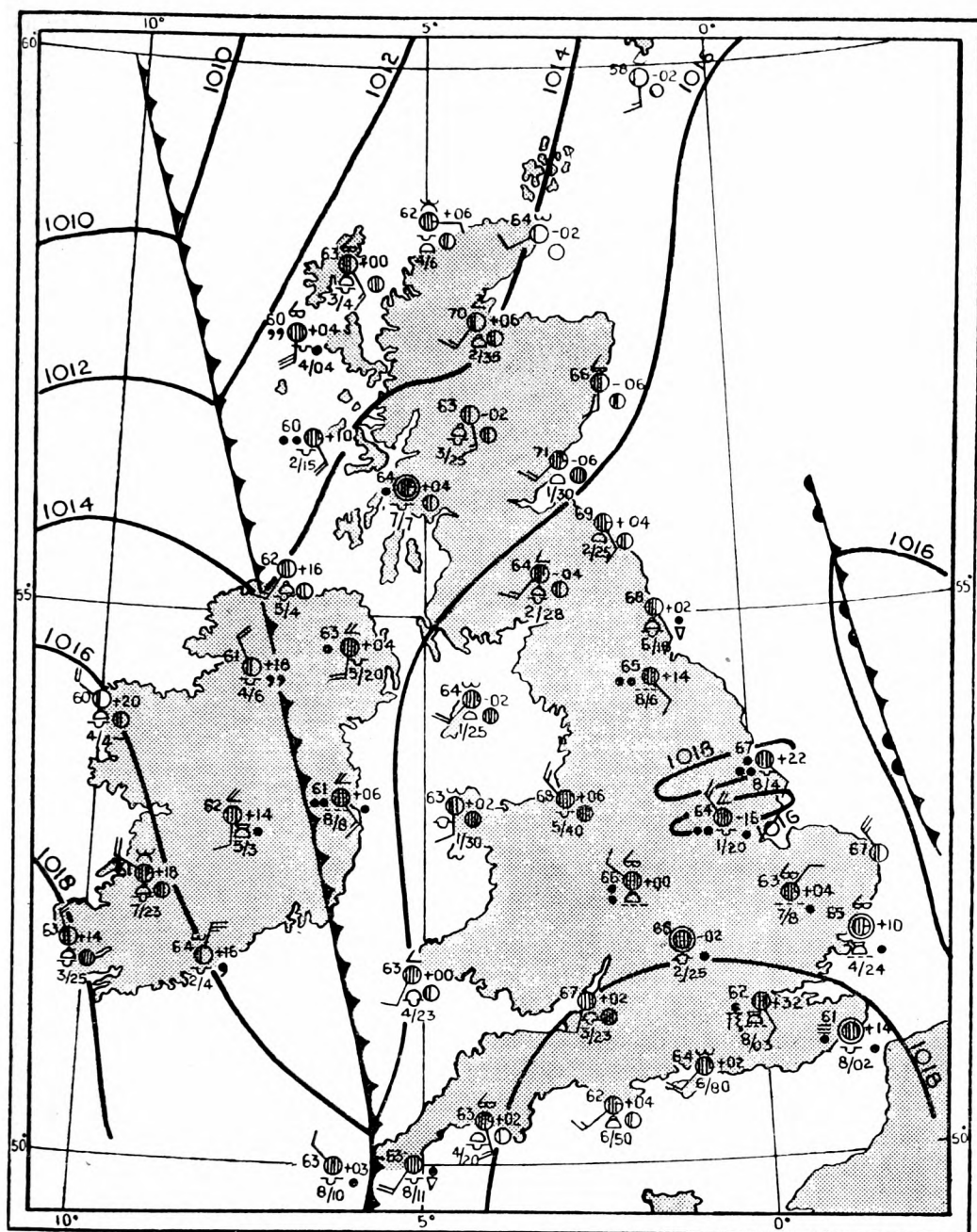


FIG. 5—SYNOPTIC CHART, AUGUST 24, 1944, 1800

Head was in the high-pressure region and Cranwell in the trough of low pressure. Elongated systems are indicated, but the material for determining their exact nature, if it ever existed, is no longer available.

The cold front of the previous day had become quasi-stationary over the North Sea by 1800 on the 24th, Fig. 5. A wedge had spread from the north and the thunderstorm system with its pressure irregularities had invaded the wedge from south-south-east. The SSE. upper wind was ahead of an upper trough, which had passed Larkhill by 1800 and which crossed south-east England during the night, with further rain. The 1800 sounding at Downham Market, Fig. 4b, shows marked instability above the 650-mb. surface.

Through the courtesy of the Directors of the French and Belgian Meteorological Offices, copies of barograph traces were obtained from the observatories at Montsouris, Paris, and at Uccle, Brussels. The Paris curve, Fig. 6, shows a rise of 5.7 mb. (4.3 mm.) between 1940 and 2000 on the 23rd, immediately followed by a fall of 2.7 mb. in 12 min. This storm affected Kent and East Anglia during the night; the fall of 4½ mb. in half an hour at Yarmouth was associated with the same storm or group of storms. There were also small irregularities at Paris during the morning of the 24th, when the storm which reached England that afternoon must have been crossing the area or developing in it. The Uccle trace also shows marked irregularities on the 23rd and 24th, in particular a large rise just before midnight.

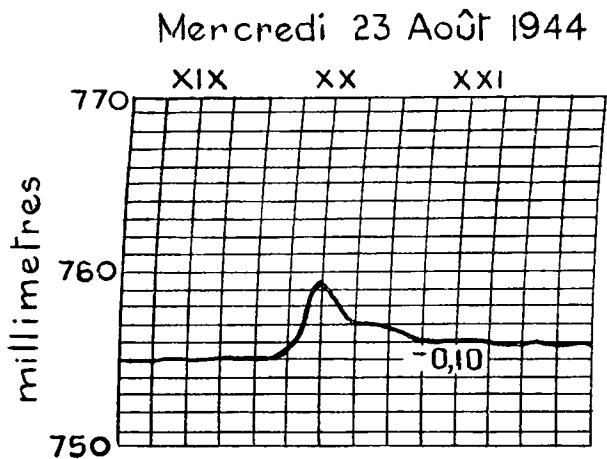


FIG. 6—BAROGRAPH TRACE AT MONTSOURIS,
PARIS, AUGUST 23, 1944

Sudden increases of pressure are typical of thunderstorms, and a subsequent fall back to, or below, the original level is quite common, though this is rarely so rapid as on August 23rd. Pronounced small troughs on the barograph are rather infrequent in our area, and are usually associated with large vertical wind shear (at least in the lower troposphere) and with medium-level instability. Considerable fluctuations may occur in these conditions even when no precipitation reaches the ground. The Killadeas case shows that medium-level instability is not an essential feature for the formation of a small low.

TABLE I—UPPER WINDS

Pressure	August 23		August 24					
	Larkhill		Larkhill		Downham Market			
	0600		1200		1200		1800	
mb.	°	kt.	°	kt.	°	kt.	°	kt.
500	160	48	160	60	150	33	260	13
550	160	49	160	59	150	26	270	13
600	160	54	160	57	160	25	260	10
650	160	55	160	53	160	20	250	9
700	150	50	160	44	170	17	250	8
750	150	47	150	43	190	17	230	8
800	150	42	160	40	190	16	220	3
850	140	32	160	36	180	12	230	8
900	130	26	160	31	180	10	240	8
950	100	17	130	27	180	9	220	7
							260	3
							340	—

NOTES ON SOUTHERN HEMISPHERE CIRCULATION

By S. T. A. MIRRLEES, M.A.

Observations in Graham Land.—Records of some two years' meteorological observations in West Graham Land, Antarctica, have been put at the disposal of the Meteorological Office by Mr. A. Stephenson, Chief Surveyor and Meteorologist to the British Graham Land Expedition, 1934–37.

Mr. Stephenson¹*, as is known to readers of this Magazine, has had considerable previous experience of “higher latitude” meteorology, and his records are more comprehensive than those of most expeditions which have not included a full-time meteorologist. War and other circumstances, however, have delayed preparation of the full meteorological account of the expedition, and this note gives the results only of a preliminary examination of some of the barometric data, directed mainly to a search for “circulation patterns”.

Barometric pressure over Graham Land, 1935–37.—Table I, which is extracted from Mr. Stephenson's notes published in the *Geographical Journal*² soon after the return of the expedition shows the mean barometric pressure at mean sea level for various months at the two bases Argentine Islands and Barry Island. Data for February 1936 are missing as the expedition was shifting camp in that month.

TABLE I—MEAN MONTHLY BAROMETRIC PRESSURE AT MEAN SEA LEVEL

A: Argentine Islands, 65° 15'S., 64° 16'W., 110 ft., March 1935 – January 1936
B: Barry Island, 68° 08'S., 67° 06'W., 50 ft., March 1936 – February 1937

	Period	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mean
		<i>millibars</i>												
A	1935–36	973.9	993.2	991.5	995.1	997.9	991.1	996.8	994.3	986.3	992.2	993.9	..	991.†
B	1936–37	979.8*	989.2	993.2	993.3	991.3	994.7	979.7	989.3	982.7	981.7	990.2	991.6†	983.

*March 12–31, 1936

†February 1–23, 1937

‡Mean of 11 months

In comparison with the data given in the standard work by Meinardus³ the range of the means for station A (24 mb.) is slightly greater than had been observed before in Graham Land. The great variability from month to month, small variability from year to year (annual pressure little different from 987 mb. (740 mm.)) and the tendency for a double annual period are characteristic of Antarctica. The mean for March 1935 (973.9 mb.) is 6 mb. lower than had been observed in Graham Land for any month before 1935.

General circulation (surface) of the “fifties” and “sixties”.—The main features of the general circulation over the region southward of South America are well known in a broad way as

(a) a region of prevailing westerly winds with mean pressure decreasing southwards;

(b) a trough of low pressure, statistically the “mean path of depressions”, somewhere between 60° and 65°S., but exactly where remains to be determined; and

(c) a region of prevailing easterlies with mean pressure increasing southwards (?) from 65°S.

*These numbers refer to the list of references on p. 321.

Up to about 1935 published data of observations for the region south of 61°S., where the most southerly fixed station (in the South Orkneys) is situated, included observations at three fixed stations for separate periods 1902-03, 1904-05 and 1908-09 and a number of "ship drifts". Synoptic charts of the southern hemisphere between 30°S. and Antarctica were published for October 1901 to March 1904 based on the results of various expeditions, but much detail remains to be filled in, particularly on the tracks and speed of travel of depressions southward of 55°S.

Comparison of data for 1935-37.—The first stage in this preliminary comparison was to collect, from the various year-books, etc., data, for the period of Table I, for as many stations as could be found for which more or less long-period normals were available. These "permanent" stations are shown in Table II and Fig. 1.

TABLE II—"PERMANENT" STATIONS FOR WHICH NORMALS ARE AVAILABLE

Station	Latitude	Longitude	Height
	S.	W.	ft.
Punta Galera	40°01'	73°44'	131
Isla Guafo	43°34'	74°45'	459
Cape Raper	46°50'	75°38'	131
Islota de Los Evangelistas	52°24'	75°06'	180
Punta Arenas	53°10'	70°54'	92
Ushuaia	54°50'	68°20'	26
Puerto Madryn	42°46'	65°02'	46
Sarmiento	45°33'	69°01'	597
Santa Cruz	50°01'	68°31'	43
Punta Dungeness	52°24'	68°26'	16
Port Stanley (Falkland Is.)	51°42'	57°51'	6
South Georgia	54°16'	36°30'	13
South Orkneys	60°43'	44°47'	23

From these data it was possible to make charts of normal and actual pressure distribution for various months, also charts of pressure difference from normal and diagrams of the departure from normal of the "gradient" between various pairs of stations (see Figs. 2 and 4).

The mean annual isobars in Fig. 1 are based on all available data whether for long periods or for single years, and the first problem for the future is whether this pattern of isobars represents long-period conditions south of 61°S. or is merely coincidental.

Examination of data for individual months gives some confirmation of the result quoted by Meinardus that there is a reverse variation of monthly mean pressure in South Polar regions as compared with northward of 60°S., but the rule is not invariable; for example, March 1935, the month of lowest pressure at station A, was also that of lowest pressure in the same period at all stations south of 50°S. except at South Georgia, and in October 1935, the month of highest pressure at all mainland stations except Punta Galera, Isla Guafo, Cape Raper, the pressure at station A was above the mean for the year. Whether the correct interpretation is that the exceptions to the rule are occasional months in which the weather systems are much larger than usual remains to be investigated.

Circulation when pressure is relatively high over Graham Land.—
 Fig. 2 is the “ composite situation ” of the six months in which pressure over Graham Land was higher than at South Orkneys. These months showed a tendency for

- (a) prevailing southerly winds at station A;
- (b) weakened westerly circulation between Guafo and Los Evangelistas;
- and
- (c) increased south-west circulation between Falkland Islands and South Orkneys and South Georgia, also between Ushuaia and South Orkneys.

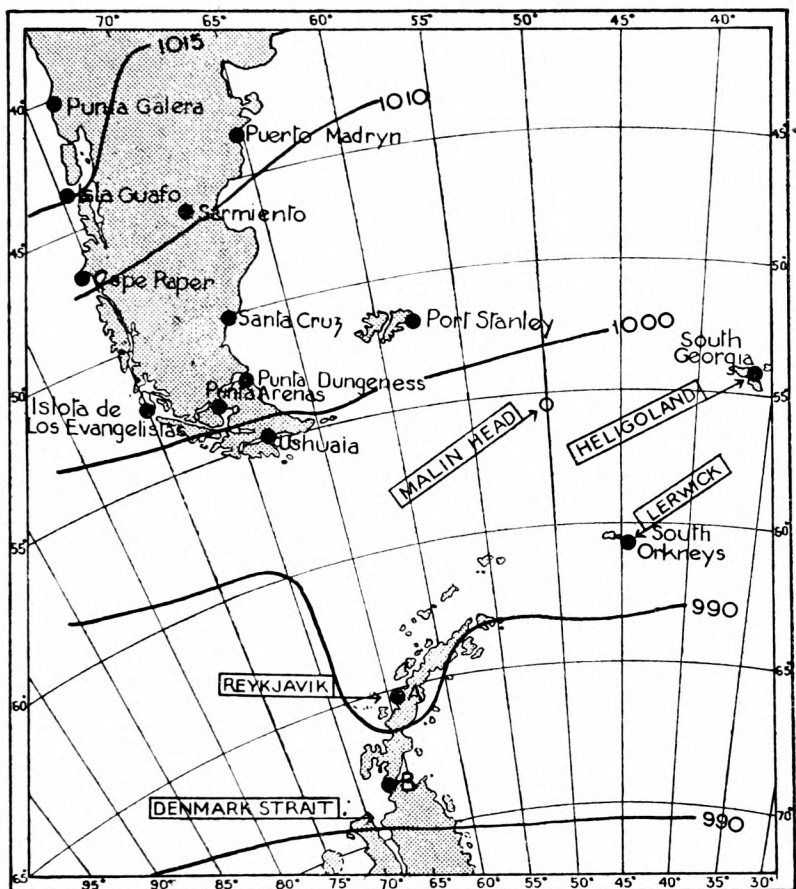


FIG. 1—ISOBARS OF NORMAL ANNUAL BAROMETRIC PRESSURE AT M.S.L.

The stations named (except A and B) are those for which normals are available. A and B mark the positions of the two stations of the British Graham Land expedition

The names of the northern hemisphere “corresponding” station inset enable comparison of relative distance to be made

A possible interpretation is that in these months there was a northward extension of the Weddell Sea low, with, on the western side of the area, either a weakening of the Bellingshausen Sea low or its displacement considerably southward and an opening out of the gradient for westerly winds between Punta Galera and Los Evangelistas, rather than a southward extension of the South Pacific high. It may be noted that the “ composite situation ” based on seven months with greatest area of positive deviation of pressure is almost identical with Fig. 2.

Circulation when pressure is generally below normal.—The reverse situation, in which pressure was below normal at 11 or more of the 13 “permanent” stations (10 months out of 24) was accompanied (in six months) by prevailing winds between E. and S. at the stations A and B, increased westerly circulation in the zone between Guafo and Los Evangelistas and decreased SW. circulation in the east of the area; further, when the westerly circulation was enhanced in both northern and southern parts of the zone (three months) the gradient for SW. winds in the east of the area was much weakened or even reversed.

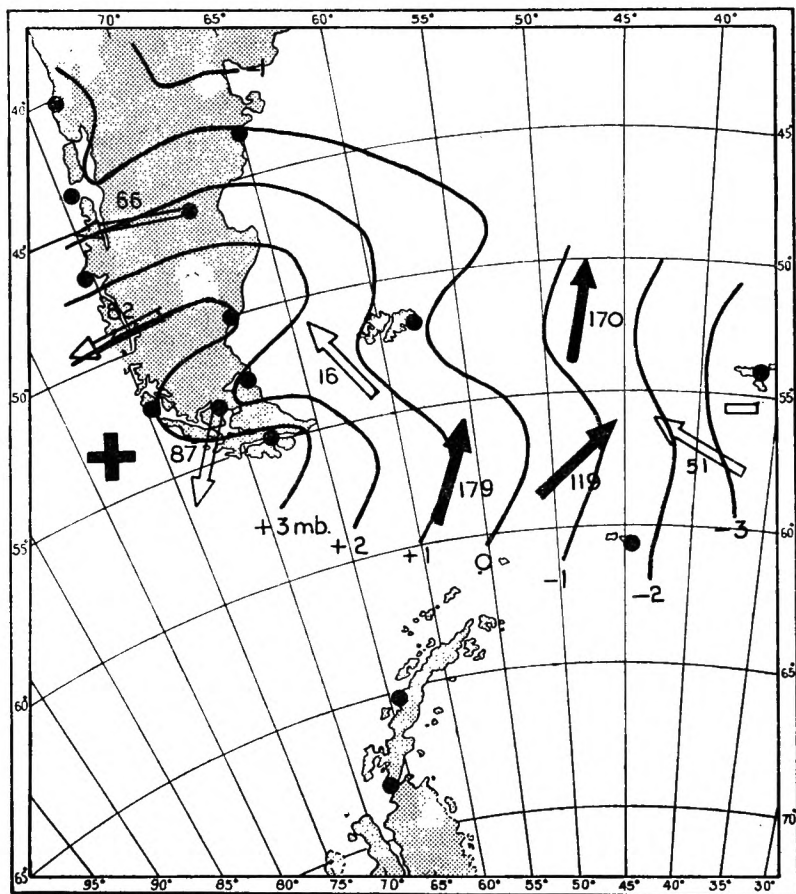


FIG. 2—“COMPOSITE” CIRCULATION PATTERN. MEANS OF SIX MONTHS IN WHICH PRESSURE OVER GRAHAM LAND WAS HIGHER THAN OVER SOUTH ORKNEYS

The continuous lines are isonormals. Arrows fly with excess (thick lines) or deficit (double lines) “gradient” between pairs of stations; the adjoining figures show the percentage of the “normal gradient”

Limitations of the data.—In view of the short period of observations, which restricts the possibility of sorting out seasonal variations, it does not seem necessary to pursue the search for “types” further on these lines; little emphasis has been laid on data of wind direction because of a statement of marked local influence at the station B.

Extrapolation of normals.—For further investigation of a circulation index it is now necessary to resort to extrapolation. In this connexion, analogy between northern and southern hemispheres is unlikely to be of much use (see Fig. 3); the superposed names of “corresponding” places of the northern

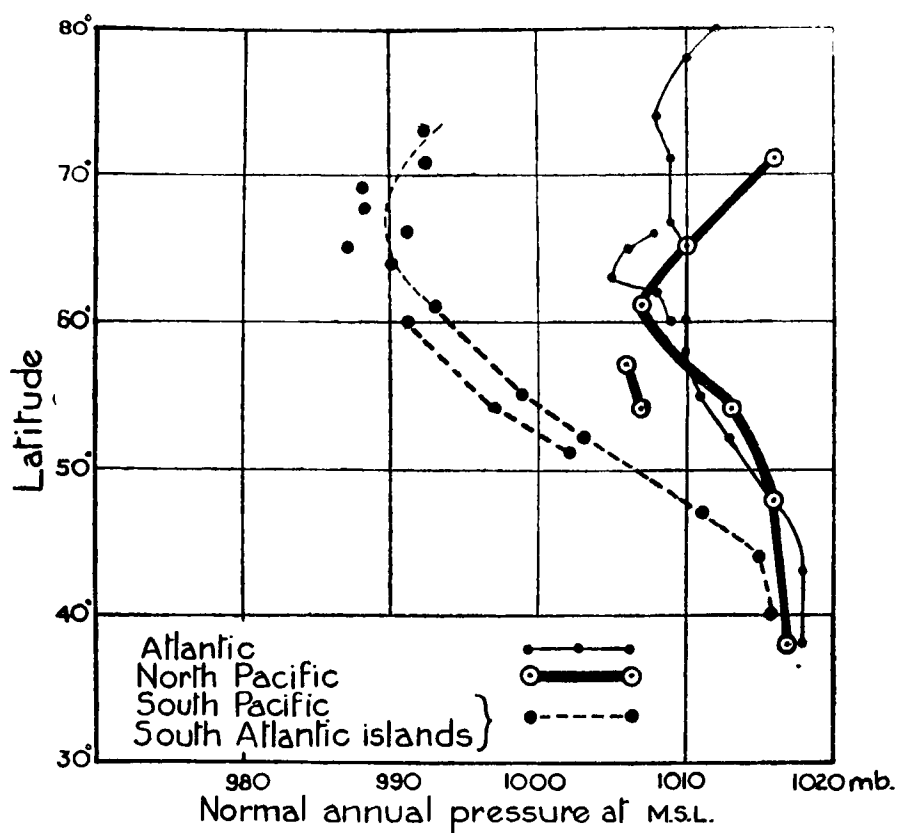


FIG. 3—VARIATION OF NORMAL PRESSURE WITH LATITUDE
IN THE NORTHERN AND SOUTHERN HEMISPHERES

hemisphere on Fig. 1 give an idea of the distances involved. With this preliminary caution and on the basis that things are simpler in the southern hemisphere one may try extrapolating over the distance from Lerwick to Reykjavik. Incidentally, the much stronger circulation of the southern hemisphere seems to be associated with a lower height of tropopause; the radio-sonde ascents made to date in the Falkland Islands have shown a tropopause height on the average 1 Km. lower than in England in the same latitude.

First, an attempt was made by extrapolating pressure-anomaly lines for all the months available, to deduce long-period normals of pressure over West Graham Land.

The results of this process are given in Table III along with other estimates quoted from text-books. The main point which remains to be settled by future observations is whether the annual minimum of pressure south of 65°S. is in November, as at South Orkneys, or in some other month.

TABLE III—ESTIMATED "NORMAL" MONTHLY SEA-LEVEL PRESSURE IN 67°S. 65°W.

Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Year	Authority
millibars													
987	990	995	992	993	991	986	991	982	991	989	991	990	
985	..	989	..	..	..	989	..	989	..	988	..	..	
..	..	..	..	..	..	..	..	..	..	990	995	..	
987	987	991	993	992	991	990	990	992	995	995	990	(991)	

- Authorities.—1. Estimated from observations 1935-37
2. From diagrams in "Handbook of meteorology"⁴
3. From diagrams in "Manual of meteorology"⁵
4. Mean of observations at Port Charcot and Snow Hill⁵

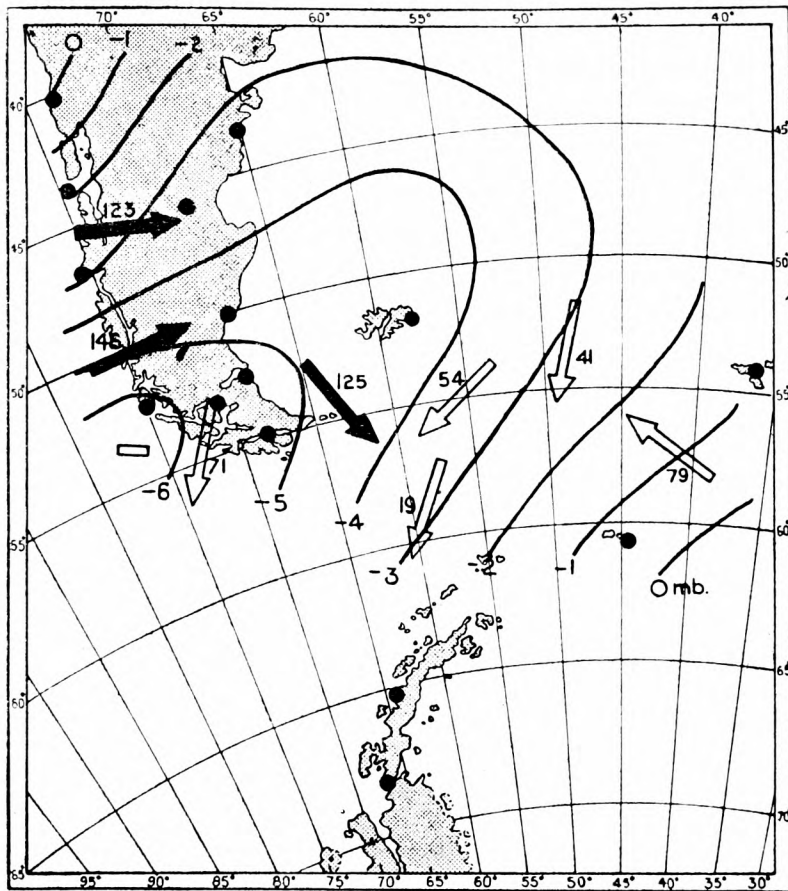


FIG. 4—"COMPOSITE" CIRCULATION PATTERN. MEANS OF SEVEN MONTHS IN WHICH THE "GRADIENT" BETWEEN GUAFO AND LOS EVANGELISTAS WAS ABOVE NORMAL AND THE BREADTH OF THE W.-WIND ZONE (SOUTHWARD OF 55°S.) WAS BELOW NORMAL
(see Table V)

Next, by means of monthly charts of normal pressure distribution and of pressure distribution in 1935-37, estimates were made of the extent of the gradient for westerly winds across the 65th meridian, south of the 55th parallel. The results are given in Table IV. Two rather slight correlations were noted in this comparison:—

(a) Months in which the W.-wind zone southward of 55°S. is above normal in both extent and intensity are months in which pressure is generally above normal over the area of Fig. 1, and

(b) Months in which westerlies are strong between Guafo and Los Evangelistas are occasions of narrow W.-wind zones southward of 55°S.

TABLE IV—ESTIMATED BREADTH OF W.-WIND ZONE

Measured across 65°W. south of 55°S.

	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
	<i>degrees of latitude</i>											
Normal	11	9	8	8	9	9	13	10	12	10	10	9
1935-36	7	10	12	3	10	7	6	10	5	3	3	11
1936-37	10	10	8	8	9	9	13	10	13	7	8	5

The "composite situation" for seven months of the second type is shown in Fig. 4; the complete frequency distribution is given in Table V, which may be interpreted as an aspect of the see-saw of pressure between lower and higher latitudes noted by various authors.

TABLE V—RELATION OF WESTERLY CIRCULATIONS NORTH AND SOUTH OF 55°S .

Mean monthly gradient between Guafo and Los Evangelistas	Above normal			Below normal		
Breadth of W.-wind zone south- ward of 55°S .	Above normal	normal	Below normal	Above normal	normal	Below normal
Frequency of occurrence	0	4	7	months		
				6	3	4

Need for further observations and investigations.—A brief examination was made of corresponding data for Reykjavik, Lerwick, Malin Head and Valentia, to see if any evidence would appear of resonance between the westerlies of the northern and southern hemispheres, but the results were inconclusive, as was probably to be expected.

The search for circulation types of the southern hemisphere described above results in more questions than answers, and some other questions, which require a "synoptic" investigation, are:—

- (a) Can the isobars of Fig. 1 be explained in terms of depression tracks, or are they merely the result of too few observations?
- (b) Is the "main track" of depressions further south than previously described? and
- (c) Are the depressions mainly complex? *i.e.* are there two main tracks, one north and one south of 65°S ?

The autographic records of stations A and B would enable a good deal of the frontology there to be deduced, but the start of a real attack on the problems of the circulation in $50\text{--}60^{\circ}\text{S}$. must await the establishment of an upper air station somewhere south of the circumpolar trough. A single upper air station would give some indications of the "vast circumpolar whirl" described in text-books, but there would still be room for extrapolation—Antarctica is about double the area of Australia.

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THE FORMATION OF A LAMINATED TROPOPAUSE AND THE MASS EXCHANGE BETWEEN THE STRATOSPHERE AND THE TROPOSPHERE

By E. KRAUS

Upper air over east Anglia at 1800 on November 9, 1944.—The immediate incentive for the writing of this note came from the demand to explain the following observations. On the evening of November 9, 1944, several aircraft reported very low condensation trails over the North Sea and East Anglia. These trails disappeared at a height of about 24,000 ft. At about 29,000 ft. the trails were again observed, and they were seen to form throughout the whole layer to above 35,000 ft., which was the highest level of observation. There were also some patches of thin cirrus in layers at about 33,000–34,000 ft.

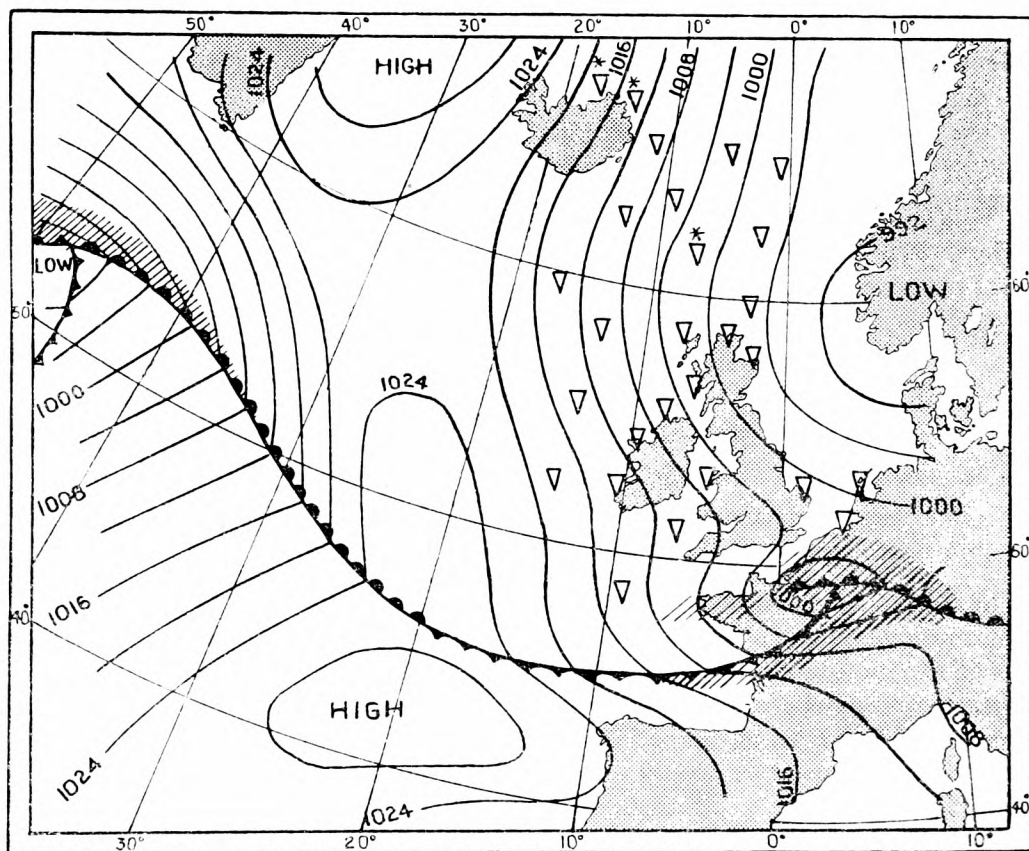


FIG. 1—SURFACE WEATHER CHART, NOVEMBER 8, 1944, 1800

The readings of the radio sounding at Downham Market at 1800 G.M.T. are representative of the air mass in which these observations were made. These values are plotted in Fig. 4. A superficial examination of the ascent curve would suggest that the pressure at the tropopause was 410 mb. and the height 21,300 ft. In the *Daily Weather Report* these values are stated to represent the tropopause. If this statement were complete it would mean that cloud existed in the stratosphere, 12,000 ft. above the tropopause. This is hardly acceptable and a further examination of the radio winds suggests a different picture.

As a rule the wind strength increases in the upper half of the troposphere. This is due to the cumulative effect of the horizontal temperature differences which give rise to a thermal wind which increases with height. In the stratosphere the thermal gradient is reversed and the wind strength decreases again. At the tropopause the values of the wind strength reach a maximum. Therefore at the tropopause we have $\partial v / \partial z = 0$ and there should be no shear across that surface.

Consider now the observed wind at Downham Market:—

TABLE I—RADIO WINDS AT DOWNHAM MARKET AT 1800 G.M.T. ON NOVEMBER 9, 1944

	Pressure (mb.)												
	900	800	700	600	500	400	350	300	250	200	170	150	130
Wind direction	320	330	330	330	330	340	340	340	340	330	330	330	320
Wind speed	42	41	53	39	56	76	92	120	104	85	53	40	38

These winds show no maximum near the apparent tropopause at 410 mb. On the contrary, there is a rapid increase of wind above that level to a maximum which seems to be between the 300-mb. and 250-mb. levels at about 30,000–32,000 ft. It follows that either the assumption of a tropopause at 410 mb. is incorrect or that the ascent pierced the tropopause again at a higher level. This question cannot be decided from local data only.

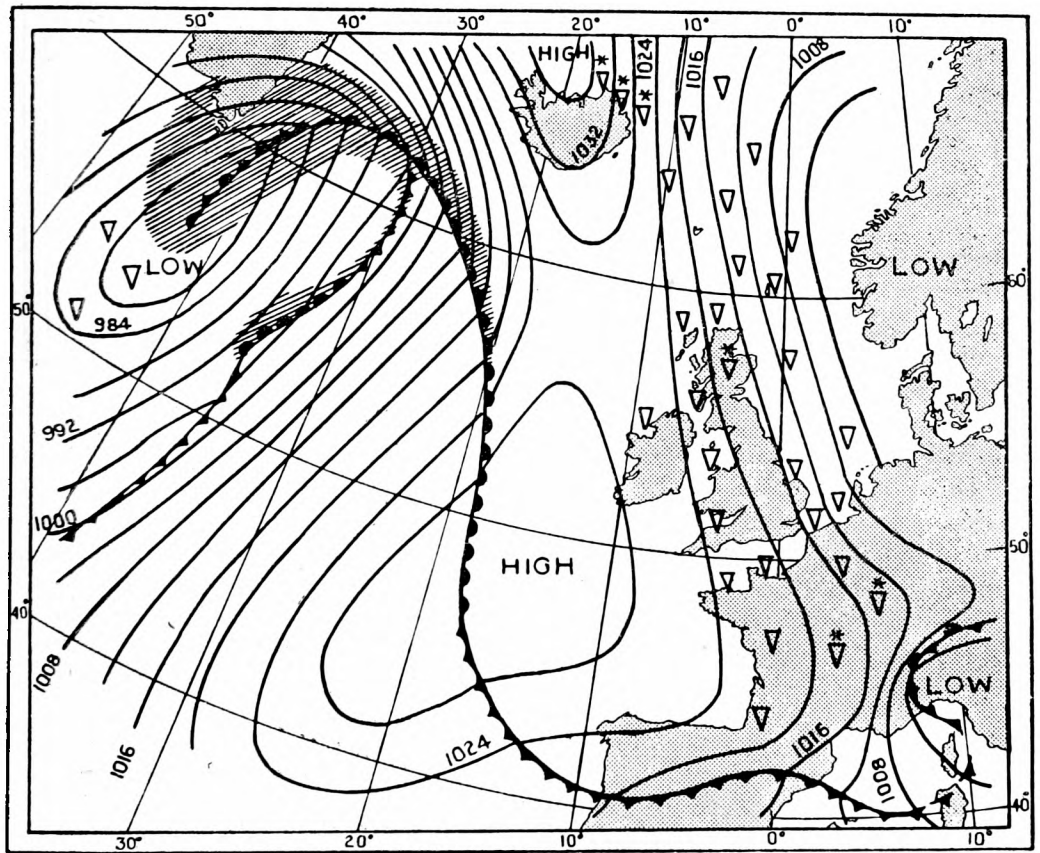


FIG. 2—SURFACE WEATHER CHART, NOVEMBER 9, 1944, 1800

Air-mass analysis.—The synoptic situation on the surface is represented by the two charts Figs. 1 and 2. On the evening of November 8, 1944, a wave depression moved eastward over France and from its centre a front curved westwards across the North Atlantic to another depression which approached Greenland from the south. At 1800 on the following day cold polar continental air in the rear of the wave had invaded Great Britain to a great depth and had broken into the Mediterranean. An anticyclone developed very rapidly to the west of Ireland and the warm front of the next depression approached Iceland.

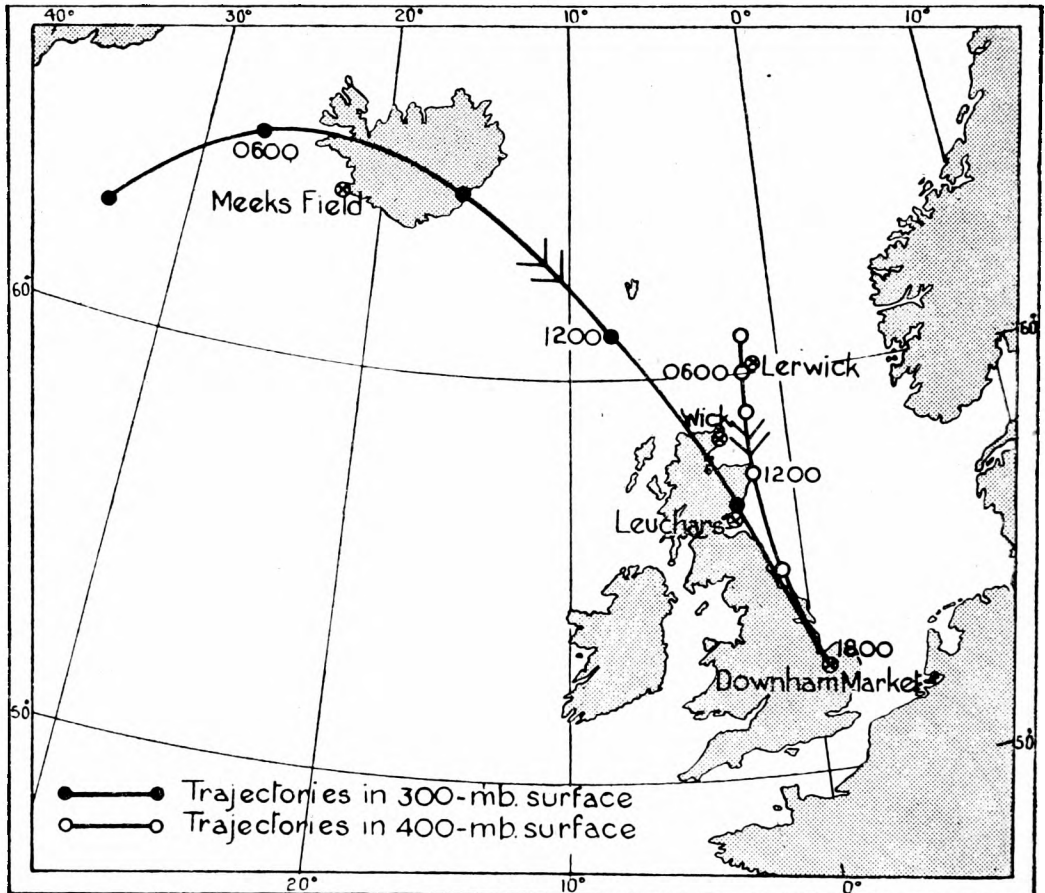


FIG. 3—TRAJECTORIES IN 300-MB. AND 400-MB. SURFACES

In order to ascertain the origin of the air which was at different heights over Downham Market on the evening of the 9th the path of the air to that place had to be reconstructed. This was done by first drawing topographic charts of the 500-, 400- and 300-mb. charts at six-hourly intervals. It was then assumed that for three hours before and after the time of each chart the displacement along the contour lines of an individual body of air occurred very nearly with the gradient wind speed. Curvature and latitude effects were duly considered. The displacement across the isobars was assumed to be equal to:—

$$\frac{1}{\lambda} \times \frac{\text{gradient wind}}{\text{geostrophic wind}} \times \Delta (\text{gradient wind})$$

In this expression λ indicates the Coriolis term and “ Δ (gradient wind)” is the



Photo by the late Mr. M. C. Gillman

INLAND CLOUD TAKEN FROM A HEIGHT OF 3,500 FT. NEAR THE ZAMBESI DELTA IN THE EARLY AFTERNOON IN MID APRIL

This photograph shows the clear lane which persists along the coast after the early morning "land breeze front" has moved inland and dissipated. The generally fair conditions shown are associated with the tendency for the weather to become settled after the moderate heavy rains which fall in this area during December to March



"LIFTING" STRATUS SEEN FROM THE SOUTH-EAST SLOPES OF THE USAMBARA MOUNTAINS ABOUT TWO HOURS AFTER DAWN

Photo by the late Mr. M. C. Gillman

This low stratus cloud forming around dawn over the high ground of east Africa sometimes disperses before the morning observation. At dawn it fills the valleys like a sheet of lifted fog and only the lower slopes are covered. At times as it lifts it blankets the higher slopes and can be rather persistent, at others it disperses quickly at low levels. It forms mainly on exposed southern and eastern slopes and breaks sharply to the lee of high ground—e.g. over the high ground to the north-east of the Eastleigh airfield at Nairobi



Reproduced by the courtesy of H. E. C. Powers

CIRCUMZENITHAL ARC SEEN FROM WOODFORD, ESSEX,
AUGUST 22, 1949, 1800 G.M.T.



Photo by the late Mr. M. C. Gillman

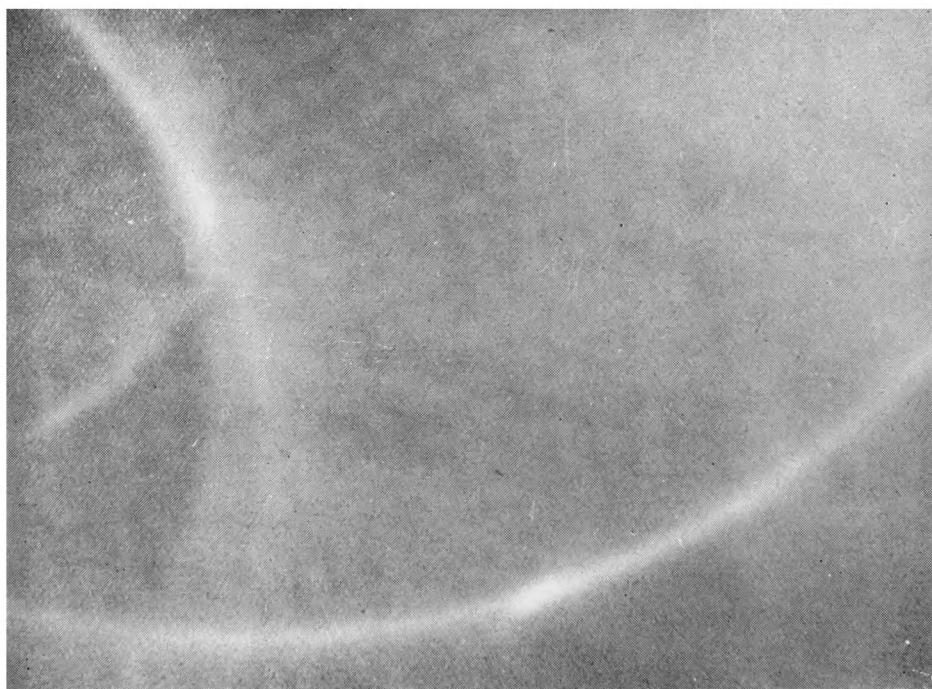
HAILSTORM FRINGE SEEN FROM TARIMI, IKOMA, AT 1700 ON JANUARY 27, 1940

The photograph shows the under mammato surface of a heavy cumulonimbus which was giving rise to a heavy shower of hail, and the effect of local winds associated with violent convection currents is clearly shown by the vegetation. The general level of the ground near Ikoma to the east of Lake Victoria is 1,500-2,500 ft. above the level of the lake (3,700 ft.) with an escarpment a short distance to the east



Reproduced by the courtesy of M. A. Gunn

PARHELIC CIRCLE WITH MOCK SUN AND LINE OF ONE OF THE SHIMMERING WAVES WHICH SWEEP ACROSS THE CIRCLE FROM THE WEST, SEEN FROM GRAYS, ESSEX, JULY 20, 1949, 1020 G.M.T.
(see p. 282)



Reproduced by the courtesy of M. A. Gunn

PARHELIC CIRCLE AND MOCK SUN WITH HALO FORMING, SEEN FROM GRAYS, ESSEX, JULY 20, 1949, 1045 G.M.T.
(see p. 282)

wind change at three-hourly intervals along the path. In computing the path in this manner it had to be assumed that an individual air parcel remained in or near the same isobaric surface. It will be proved below that this assumption was justified in the present special case. The error which is due to the neglect of other small terms should be smaller than that caused by the inaccuracy of the upper air charts.

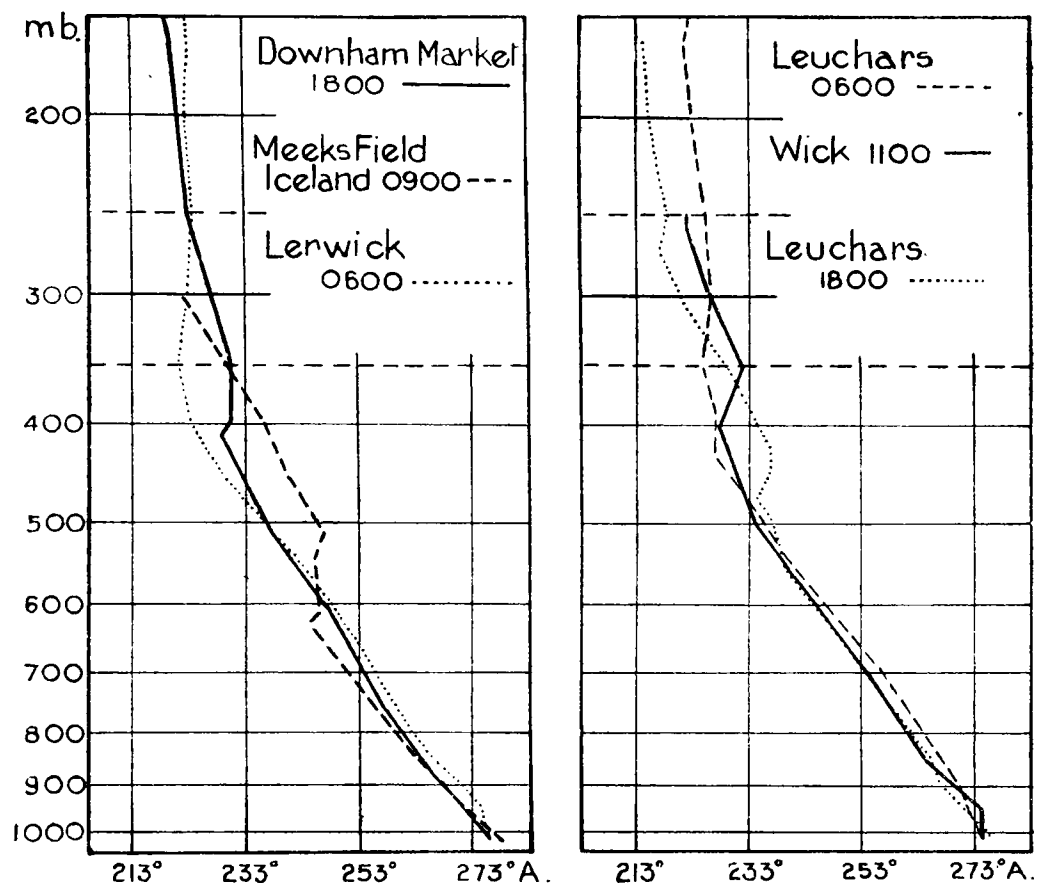


FIG. 4—UPPER AIR ASCENTS, NOVEMBER 9, 1944

The result of the computation is demonstrated in Fig. 3. The air which was over Downham Market at 1800 in the 400-mb. surface slightly above the tropopause was three hours earlier just off Newcastle, and at noon it must have been to the north-east of Aberdeen. The 400-mb. chart for 1200 gives relatively slow wind speeds in that area, and we are led back to a point near Lerwick in the Shetland Isles from where the air must have come six hours earlier, at 0600. At that time the Lerwick radio-sonde indicated slack northerly winds at all heights; at the 400-mb. level the actual values were 360° 13 kt. The curve of the ascent has been plotted on Fig. 4. There seems to be little doubt that the whole air column over Lerwick was of polar origin (polar continental air). The tropopause is at 400 mb. At Downham Market twelve hours later at 1800 it was found to be at 410 mb. It follows from hydrodynamical considerations that the air which is at one time in or near the tropopause should be always near this surface. The assumption that a parcel of air, which was at 0600 at the 400-mb. level over Lerwick, travelled to Downham Market in or near the same pressure level appears therefore justified.

The path in the 300-mb. surface is very different from that in the 400-mb. surface and all lower levels. It should be viewed together with the surface weather charts (Figs. 1 and 2) for it shows the large displacement and the anticyclonic curvature which is typical of the air above a warm front. In twelve hours the air must have covered some 1,400 miles. Because of the lesser accuracy of the upper charts over the North Atlantic the path in the 300-mb. surface cannot be established with the same confidence as that in the 400-mb. surface which was close to the dense aerological network of the British Isles. However, it can be stated with confidence that the position of the air at 0600 was within a 200-mile radius, about the position given in Fig. 3. The whole of western Iceland appears to have been covered at that time by frontal altostratus or cirrostratus, which indicates the presence of warm air aloft. This is confirmed by an examination of the ascent at Meeks Field (Fig. 4), which shows a clearly-marked warm front between 627 mb. and 512 mb. Above the 512-mb. level the sounding reached genuine tropical maritime air. In this air mass was the origin of any sample of air which might have been taken from the 300-mb. surface over Downham Market at 1800 on the same day.

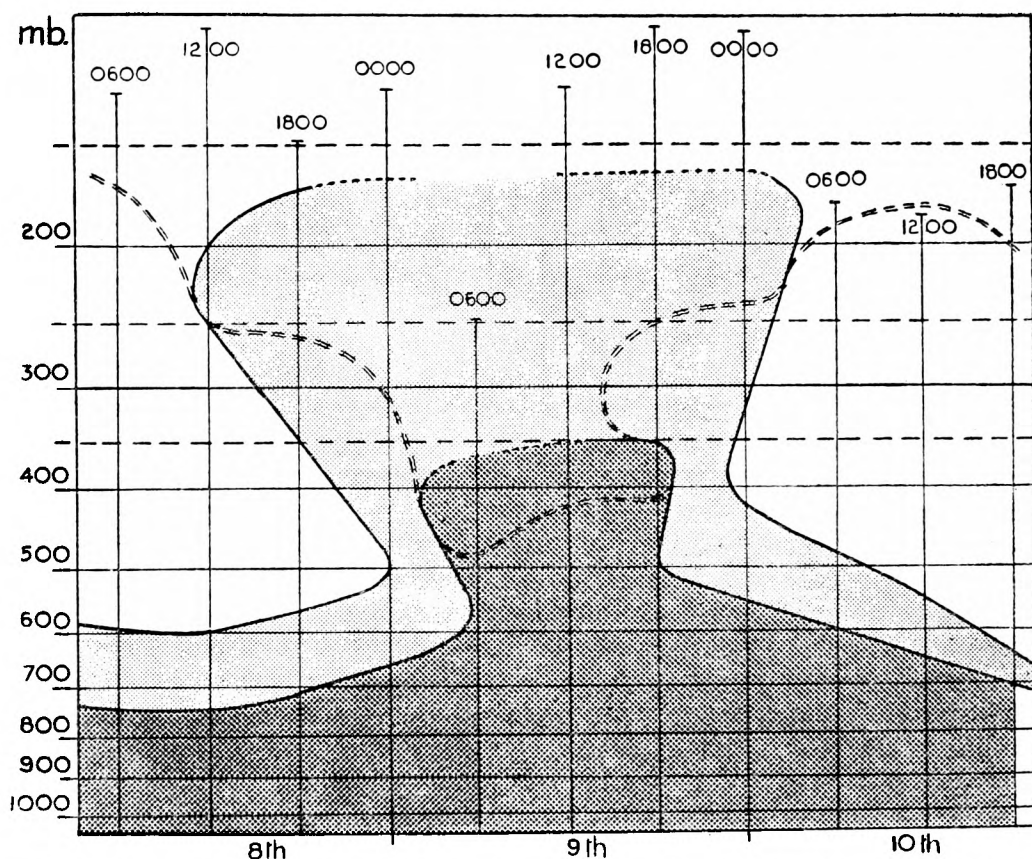


FIG. 5—VARIATION OF THE TROPOPAUSE WITH TIME OVER DOWNHAM MARKET, NOVEMBER 1944

In this way it has been established that on the evening of November 9, over Downham Market the air at 300 mb. was tropospheric air of tropical origin, whilst at the 400-mb. level there was stratospheric air of polar origin. This gave rise to the observed phenomena which were described at the beginning of this note.

There is no evidence that the lower air mass became again uncovered during its further journey. On the contrary, the analysis of the upper charts suggests that the polar air in the 400-mb. surface was the following morning somewhere near Karlsruhe or the northern Black Forest. Whilst travelling there tropical air must have been streaming constantly above it. This is again confirmed by observations from aircrews who reported wispy cirrus and condensation trails above 29,000 ft. in this area on the morning of the 10th. The lower belt of condensation trails had vanished, and it seems that the lower branch of the tropopause, which separated the polar tropospheric from polar stratospheric air, had become diffuse and had lost its character of a discontinuity of the temperature gradient.

The gradual appearance of tropical air aloft is confirmed by an examination of the Scottish ascents which are plotted on the right-hand side of Fig. 4. At 0600 the ascent over Leuchars was made entirely in polar air very similar to that found over Lerwick at the same time. At 1100 tropical air was over Wick above the polar stratosphere at 350 mb. By 1800 the thickness of the tropical air had considerably increased and it was found down to 420 mb. over Leuchars.

Air masses over Downham Market between November 8 and 10.—

The passage of the different air masses over Downham Market is illustrated by Fig. 5 and Fig. 6. In Fig. 6 the abscissa has a temperature scale but each successive ascent is displaced by 10°A. to the right; the slanting lines indicate potential temperature; the single arrows give the upper and lower boundaries of the frontal zones, and the double arrows show the height at which the various ascents pierced the tropopause. In Fig. 5 the abscissa has a time scale. The individual ascents are indicated by the vertical lines. The broken double line represents the tropopause and its variation with time. The dark area indicates genuine polar air; the frontal transition layer appears in a lighter shade and the genuine tropical air has not been shaded at all.

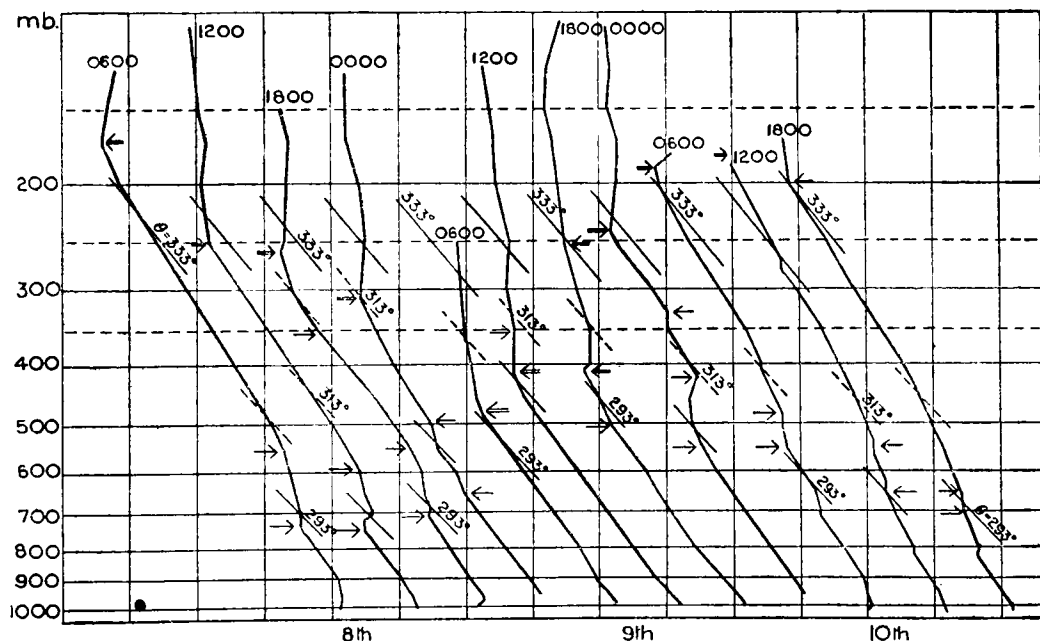


FIG. 6.—DIAGRAM ILLUSTRATING THE PASSAGE OF DIFFERENT AIR MASSES OVER DOWNHAM MARKET, NOVEMBER 1944

In the troposphere the frontogenetic processes bring air masses of very different temperature into juxtaposition; therefore we find frequently a narrow zone of very rapid temperature transition which may be called a frontal zone—or in abstraction—a frontal surface. In the stratosphere the horizontal temperature gradient is much weaker, and the horizontal convergence is also much smaller than in the troposphere where it is mostly associated with the rapid up currents of saturated air which do not exist in the stratosphere. Therefore the transition between the air masses is much more gradual, and this is brought out in Fig. 4 by the greater thickness of the transition layer in the stratospheric air.

A more detailed examination of the two diagrams shows that during daylight on November 8—whilst the wave depression which is shown in Fig. 1 was over France—the ascent reached genuine tropical air at about 600 mb. During the night the wave moved away towards the east, and in its rear the depth of the cold air increased rapidly. Transitional stratospheric air appears for the first time aloft in the 1200 ascent. In this transition layer the potential temperature of the tropopause decreases from 337°A . in the genuine tropical air to 313°A . at midnight. At 0600 on the following day the whole ascent is in polar air and the curve of state at that time and at 1200, is almost identical with those found at Lerwick and Scotland in the same air mass. The potential temperature of the tropopause in this polar air is 43° lower than it was twenty-four hours earlier in the tropical air. The re-appearance of tropical air above the polar tropopause at 1800 has been described above. With the slow approach of the warm front from the west the depth of the tropical air increases again, and at 0600 on November 10, the sounding indicates tropical air above 480 mb.; the tropopause has again a potential temperature of 335°A . During the whole development the winds above 200 mb. were relatively slight, and it is reasonable to assume that no real change of air-mass type occurred at very great heights.

The analysis which is presented by Fig. 5 has been fairly well established by the laborious method of trajectory construction, and the investigation of a great number of ascents of which a small fraction only is shown here. It is quite impossible to identify air masses from single observations of the pressure and temperature. This is due to the fact that in the stratosphere, relatively small vertical displacements will cause greater temperature changes than very large horizontal displacements. A simpler method of air-mass identification in the stratosphere may become possible when additional data such as accurate humidity observations become available.

Horizontal convergence in the polar air.—It has been stated above that the lower branch of the tropopause appears to vanish during the further development. Such a dissolution may be due partially to the changed radiational conditions which must be very different from those at the origin of the polar air in higher latitudes. Radiation acts relatively slowly, however, and there is evidence that kinematic effects are more important in the present case. It is well known that vertical divergence in a layer of air causes the vertical temperature gradient to approach the adiabatic lapse rate, and that it tends to smooth out pronounced changes of the lapse rate. Vertical divergence therefore favours the disappearance of a tropopause. In the free atmosphere vertical divergence of any extent is always associated with horizontal convergence, and for that there is ample evidence in our example.

In the first instance it can be observed that the surface pressure is rising briskly over the whole area where the multiple tropopause has been observed or may be expected (*Daily Weather Report*). Theoretically it has been demonstrated by Sutcliffe, Bjerknes and other authors that rising pressure on the ground is always associated with horizontal convergence and vertical divergence aloft. In our special case an analytical proof of horizontal convergence at the level of the polar tropopause is given by Fig. 7 which represents the trajectories of three elements of air which were at 1800 on November 9 over Larkhill, Liverpool and Downham Market respectively. The successive positions on these trajectories determine triangular areas. At a first approximation of Green's theorem it can be stated that the shrinking of these areas will be roughly proportional to the horizontal convergence in the moving air. On the diagram it can be seen immediately how important this effect is. Hence we can conclude that there must have been a strong vertical divergence which should have favoured a rapid dissipation of the polar tropopause.

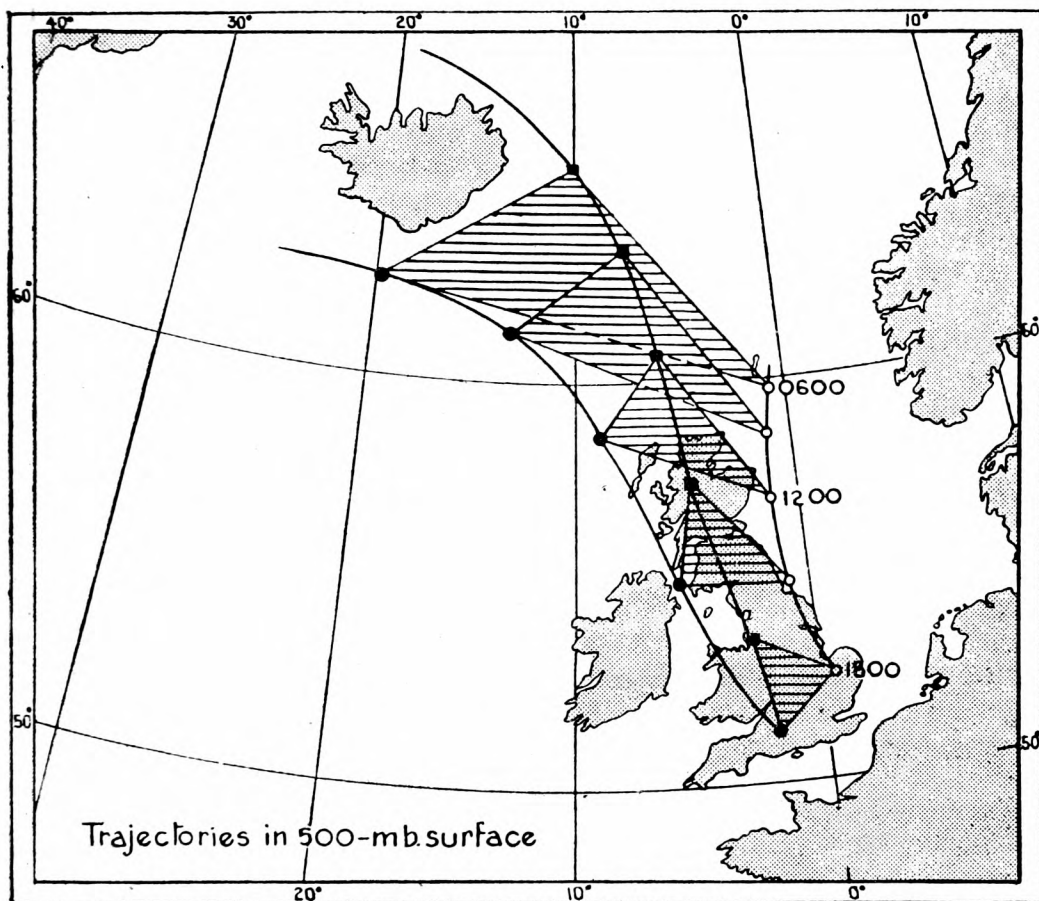


FIG. 7—TRAJECTORIES OF 3 ELEMENTS OF AIR WHICH WERE OVER LARKHILL, LIVERPOOL AND DOWNHAM MARKET AT 1800 ON NOVEMBER 9, 1944

It should be borne in mind that the frontal surface intersects the triangles; for the air parcel which moves through Downham Market is of polar origin, whilst the air which passes Larkhill and Liverpool is from a tropical air mass. Horizontal convergence is always associated with an active front which could

otherwise not resist the dissipating effect of turbulence. At a higher level, in the 300-mb. surface, the entire sheet of air over the three stations is of tropical origin. It has been shown in Fig. 3 that at this height the air over Downham Market came also on an anticyclonically curved path from the Iceland region. The three trajectories in that surface are nearly parallel, and in view of the inaccuracy of the upper air charts it is not possible to state with confidence whether shrinking or spreading occurred. However, any change in the 300-mb. surface is incomparably smaller than the rate of the horizontal shrinking at the 500-mb. level and it cannot affect materially the tropopause in the tropical air.

General deduction.—In the preceding investigation of a special case it has been established that tropospheric air of tropical origin over-ran stratospheric air of polar origin. In the subsequent development the lower polar branch of the tropopause was dissipated, and the stratospheric air masses were thus drawn into the tropospheric circulation. Synoptic situations of a similar type are relatively frequent, and it appears reasonable to assume that they will often produce a similar effect. We are justified in generalising that stratospheric air will be transformed into tropospheric air and ozone will be transported into the troposphere during synoptic situations which are characterised by an outbreak of cold air, associated with a rapid anticyclonic development and with the presence of tropical air at great altitudes.

The opposite transformation which has been investigated in Norway can be expected above old occluded depressions. In these vortices tropical air is raised from the ground and comes finally into a position above a polar tropopause. In this case there will be vertical convergence and horizontal divergence at medium levels, which will cause the polar tropopause to become more pronounced. Radiational conditions presumably tend in this case to transform the raised tropical air into polar stratospheric air. In this way a certain amount of water vapour, dust and carbon dioxide is transported into the stratosphere.

The dissipation of one branch of an overfolded tropopause will interrupt the initial continuity of that surface and produce the laminar structure of a multiple tropopause which has been described by several investigators (*e.g.* Bjerknes and Palmén).

PROBLEM OF ARTIFICIAL CONTROL OF RAINFALL OVER THE GLOBE

By Dr. TOR BERGERON

The eminent Swedish meteorologist Dr. Tor Bergeron, Professor of meteorology at Uppsala, lectured to the staff of the Meteorological Office on the subject quoted in the title on September 15, 1949. Dr. Bergeron's lecture was based on his articles of the same title in *Tellus*, 1, No. 1 and No. 3. Only a brief report can be given here. The Director, in introducing Dr. Bergeron, referred to him as a great authority, possibly the authority, on processes of the releasing of precipitation from clouds.

Dr. Bergeron opened by saying that there was now a possibility of controlling the weather to some extent, and that he did not suppose the problems of doing so would be found any less difficult by meteorologists than those of forecasting it.

So far the only attack had been on the inducing of precipitation by dropping artificial nuclei into the clouds, though in time man might, for instance, warm the oceans by atomic energy to promote evaporation.

He pointed out that in general only those cloud forms which had a composition such that there were marked differences between the individual particles so that some particles tended to evaporate and others to grow by condensation (thermodynamic instability) were capable of producing appreciable precipitation, and further, this state necessitated the presence of water in all three phases at a temperature below 0°C . in order to be quite efficient. Slight thermodynamic instability can exist in clouds composed wholly of water-drops, owing to temperature differences, but serious instability demands the co-existence of ice crystals and supercooled water-drops. Natural formation of ice particles occurs at temperatures below, say, -10°C . The effectiveness of ice particles, whether natural or artificial, in producing rapid diffusion of the water of the supercooled droplets on to themselves and their subsequent precipitation depends partly on the temperature but largely on the ratio of the number of droplets to the number of ice crystals in a given volume. If this ratio is low (≤ 1) the cloud will presumably be rapidly transformed into one composed of many little ice crystals, as in cirrostratus, and of no value for precipitation (overseeding), and if it is high (10^8) the small number of ice crystals will certainly grow rapidly but they will soon fall out producing insignificant precipitation. The optimum ratio is not determined yet but may be about a thousand.

Artificial seeding has little or no value for producing precipitation from ordinary stratiform clouds, since the condensation process within them is too feeble. Seeding also has little value in the case of cumulus, since clouds which do not extend above the freezing level are unaffected, and those which do extend above the freezing level usually precipitate naturally. The seeding of frontal clouds is hardly practicable, since it would involve lengthy and widespread seeding. The best prospect for seeding seems to be with cloud produced by strong upward motion more or less fixed in space and extending above the 0°C . level but not reaching the -10°C . level. These conditions are fulfilled by some kinds of orographic cloud, and to these Dr. Bergeron next directed attention.

He pointed out that for heavy precipitation there must be a releasing region within a cloud or a cloud system to produce the necessary ice nuclei for seeding and a producing region below it where great amounts of condensed water are made available for seeding and precipitation. Outside the tropics very heavy precipitation requires low cloud formed by an intense updraft at high temperature in continual contact with an upper cloud or part either above the -10°C . level or artificially seeded. In the ordinary cumulonimbus these regions are part of the same cloud but this need not be so in every case.

The possible association of these two regions with separate cloud systems was well demonstrated by the very heavy precipitation over the coast of south-east Norway on March 24-27, 1927. On this occasion the seeding region was an upper frontal cloud system associated with a front well to the south-west and not, in itself, producing much precipitation over southern Scandinavia. The producing region was the cloud formed in a strong low-level air stream

forced to flow from north-east along the coast of south-east Norway as it was too stable to flow up over the main mountain range. The cloud in this north-east flow was formed by frictional convergence in a stream flowing roughly along the topographic contours. Neither system by itself would have produced the fall of snow equivalent to 201 mm. (7.9 in) of water which fell in the three days at a point on the coast.

Dr. Bergeron then turned to an even more striking illustration of orographic precipitation. He explained that frictional convergence, in statically stable air streams flowing roughly parallel to even a low coast line with higher pressure over the land, can produce a coastal maximum of precipitation. This was well illustrated by the heavy maximum of precipitation over the coastal dunes of Holland on October 25-26, 1945. Next day the wind changed to WSW. behind a cold front, the air became unstable and the distribution of precipitation quite different.

Such orographic cloud systems if lacking an efficient natural release or region represent just the clouds in which artificial seeding might materially increase precipitation because condensation may for a long while remain strong and stationary. However, an increase in coastal precipitation would diminish precipitation inland where it is more useful, so that it would be better, if possible, to oversee coastal cloud systems so that a coastal maximum is avoided and try to have the most efficient ratio of ice particles to water droplets further inland to ensure that the generally drier inland regions obtain a good supply of moisture and an effective release of precipitation. The lecturer drew attention to the difficulties, both technical and political, which attempts to regulate precipitation in this way were liable to create.

Dr. Bergeron pointed out that it was known that the ordinary theory of orographic precipitation which gave an increase with height was not in many cases supported by the evidence, several cases of which he quoted, *e.g.* the case of March 1927 just mentioned, but until the modern ideas on cloud structure were developed it was not possible to make a rational attack on the problem.

Dr. Bergeron concluded his lecture by showing a number of beautiful coloured slides taken by himself illustrating numerous cloud types from mother-of-pearl clouds down to frontal low cloud with rain, the changes which take place in visibility in central Sweden with change of air mass, and others of meteorological and scenic interest taken in the United States.

The Director, thanking Dr. Bergeron for his lecture, said he had given his hearers much to think about, and mentioned the apparent simplicity of the work described, once it had been thought out by the master.

INSTITUTE OF NAVIGATION

Two papers by members of the Meteorological Office were read at a meeting of the Institute of Navigation held at the Royal Geographical Society on May 20, Sir Robert Watson-Watt in the Chair. The first paper entitled "Equivalent headwinds on air routes" by A. F. Crossley was read by Mr. N. E. Davis. The work which this paper describes originated from requests from aircraft designers and from planning sections of air lines, notably British Overseas Airways Corporation, for wind information on world air routes at heights up to 40,000 or even 50,000 ft. The first thing was to prepare seasonal charts of contours of pressure surfaces at 700, 500, 300 and 200 mb. from which the mean

vector wind at any point could be obtained by application of the geostrophic formula, supplemented within the tropics by charts of mean stream-lines and isopleths of speed; also charts of the standard vector deviation of wind were prepared for the same levels. This work was carried out by C. E. P. Brooks, C. S. Durst and others, and is being published as *Geophysical Memoirs* No. 85. The charts express the basic wind information at any point in terms of only two variables, the mean vector wind and the standard vector deviation. The application of information of this type to provide statistics of wind on air routes in a form suitable for immediate application to air operations was worked out by A. F. Crossley and J. S. Sawyer, and a detailed account will be found in *Meteorological Reports* No. 6, now in the press. The present paper is for the most part a simplified account of that report.

An equivalent headwind (or tailwind) on an air route is defined as that constant wind which, directed everywhere along the track, results in the same ground speed as that attained with the actual system of winds. The paper shows how to calculate the mean equivalent headwind over a route in any season from the basic charts mentioned above, and further the calculation of the frequency distribution of equivalent headwinds was explained. Thus the planner is provided for any route with a seasonal mean value and also with the values of equivalent headwinds exceeded on any specified percentage of occasions. In this way he obtains the effective wind for which allowance has to be made in maintaining any required regularity of service. The calculations are generally made for an assumed airspeed of 200 kt., but the results apply with little or no variation to a range of about 150 to 300 Kt.; for higher airspeeds and suitable modification is required. Slides were shown illustrating the calculations and results for a route across the North Atlantic, and also showing a comparison between the statistical estimates and equivalent headwinds actually experienced by British Overseas Airways Corporation. Among several contributors to the discussion, Mr. E. Gold questioned the accuracy of the charts of stream-lines in the tropics where so few observations are available, and Mr. E. S. Willey of British South American Airways asked for information on the accuracy of estimates of equivalent headwinds. Replying to the discussion, Mr. Crossley said that the charts of tropical stream-lines were based on all available information and care was taken that, together with the pressure contour charts of the world, they presented a self-consistent picture of the distribution of wind. Mr. Durst remarked that although the charts were admittedly imperfect they had to be produced and were the best that could be made with present data, but they would be improved later when more upper air information had come to hand. Mr. Crossley went on to say that figures for equivalent headwinds over a route of length 1,000 miles or more would be more accurate than the values of mean winds at particular points. It was considered from experience of a few comparisons with operating statistics that the mean equivalent headwind in a season was in general correct to within 5 kt. at 10,000 ft. and to within 10 kt. at 20,000 ft. but that greater errors might occur at higher levels.

The second paper on "Jet streams and their importance to navigation" by C. S. Durst and N. E. Davis was read by Mr. Durst. A jet stream was defined as a very fast-moving stream of air found at levels between about 15,000 and 40,000 ft. The high velocity extends for a great distance downwind, but laterally there is a sharp decrease across the borders of the jet, especially

on the poleward side, where in some cases the speed falls off by as much as 100 kt. in 100 miles. In the vertical the speed may increase by 80 kt. in a height interval of 12,000 ft. below the centre of the jet, but there may be still more abrupt changes elsewhere. The movement of the stream itself consists of an extension downwind combined with a slow transverse displacement of the order of 10 kt. Synoptically, jet streams are found in the upper troposphere of middle latitudes on the warm-air side of the frontal surface between tropical and polar air masses, and the most rapid change in wind speed occurs at the passage through the frontal surface. To obtain the close juxtaposition of tropical and polar air it is necessary to have either a closed cyclonic circulation aloft in the polar air or a closed anticyclonic circulation aloft in the tropical air, either of which entails a deep penetration of polar air into lower latitudes or of tropical air into higher latitudes. Mr. Durst said he first noticed these fast narrow streams while examining charts for 225 mb. over north-west Europe, but subsequently it was learned that similar features had recently been reported by meteorologists in the United States of America and the name jet stream had originated there. Diagrams of vertical sections through jet streams and of corresponding synoptic charts were shown on the screen. From these it appeared that speeds of 100 kt. or more were to be expected in a jet, while the greatest speed shown in these diagrams was 178 kt. (Downham Market, January 3, 1943, at about 25,000 ft.).

The importance of jet streams in navigation and forecasting arose not only from the high wind speed but also from the small lateral extent of the jet, since on this account they can easily be either overlooked or their importance exaggerated according as to whether observations of wind are obtained from within them or not. Mr. Durst, referring to the dispersal of our aircraft during a certain mass raid on Berlin, said this was due to an unforeseen jet stream, and G./Capt. Barrett later commented that some of the winds found by the navigators on that raid were so unexpectedly high that they were disregarded, although they were actually correct.

Mr. E. Gold referred to a zeppelin raid against this country in 1917 when the airships were scattered southwards over France, and declared that that was the first case in which a jet stream had seriously interfered with military operations.

Mr. J. Durward claimed that the first measurement of wind speed in a jet stream occurred on October 22, 1925, when a pilot balloon released from Calshot was seen to fall four hours later at a point 570 miles to the east, giving an average speed for the flight of 143 m.p.h. and an inferred wind of 180–200 m.p.h. at 30,000–35,000 ft.

Mr. E. S. Willey asked if intense gustiness at high altitudes was associated with jet streams, and, in reply, Mr. Durst agreed that was to be expected on account of turbulence which would be set up by the strong shear on the poleward borders of the jet stream, but that nothing had yet been published on this.

An interesting and instructive meeting terminated after several other speakers had taken part in the discussion.

ERRATUM

SEPTEMBER 1949, page 264, line 5; for " $t_3 = 23.47 T_5 + 1,884$ " read " $t_3 = 23.47 T_5 + 11,884$ ".

OFFICIAL PUBLICATION

The following publication has recently been issued:—

Percentage frequencies of various visibility ranges at certain places in the British Isles between the years 1927 and 1936.

The tables in this publication give the monthly, seasonal and annual percentage frequencies of the visibility ranges adopted by the International Commission for Air Navigation. The seasons are defined as Spring—March, April, May; Summer—June, July, August; Autumn—September, October, November; Winter—December, January, February. The stations used are the synoptic weather reporting stations of the British Isles with a few additional stations from which comparable observations were available, and the period covered is the ten years 1927 to 1936. For each station a table shows the frequencies of visibilities for the three hours, 0700, 1300 and 1800 G.M.T., and the distances of the actual visibility objects limiting the ranges are shown at the foot of the page.

LETTER TO THE EDITOR

Dust devils at Shawbury

In a letter published in the July *Meteorological Magazine* a description is given of dust devils at Dublin Airport. The following account of a similar phenomenon observed at Shawbury on July 12, may be of interest.

At 1400 G.M.T. an eddy was rendered visible approximately 70 yd. north of the meteorological office not by dust but by loose paper which was raised to a height of approximately 200 ft. The paper included large sheets of newspaper and a very marked cyclonic rotation was set up, the width of the cylinder being estimated to be about 30 ft. The phenomenon persisted at the same intensity for some ten minutes during which time it moved very little. At 1410 the eddy moved some 40 yd. to the north-west and collapsed rapidly.

The weather at the time was fair with 5 oktas of cirrus cloud and a north-easterly surface wind of 2 kt. The dry-bulb temperature was 85.1°F. with a wet-bulb temperature of 65.9°F.

Mr. D. Bright, a farmer, has since reported that a similar case occurred some ten miles to the north-west of Shawbury approximately half an hour earlier. While he was engaged in clearing a field of "rakings" from a mixed crop of oats, peas and vetches he observed an eddy with a counter-clockwise rotation, lifting the "rakings" to a height of some 60 ft., the width of the cylinder being estimated as 15 ft.

G. A. WILLIS

Shawbury, Shrewsbury, July 13, 1949

NOTES AND NEWS

Effect of heated glasshouses on minimum temperatures in a nearby screen

The Stevenson screen at Wye College is about 21 ft. west of the near wall of a large glasshouse running roughly north-north-east to south-south-west. This glasshouse is some 8 ft. high to the ridge, which is about 28 ft. from the

screen. A larger house runs parallel to the first; this is 18 ft. high to the ridge, which is about 66 ft. from the screen. These glasshouses are kept at 55–60°F. in winter and it was thought that the screen temperatures may be affected by their proximity. The effect was investigated in the following way.

It is known that the glasshouses were erected about 1935, and records from the screen are available for the period 1925–44. Average temperatures for Wye are published in “Averages of temperature for the British Isles for the periods ending 1935”, and deviations of the mean daily minima from their respective averages were computed for each of the months November to April over the period 1925–44. The average daily minimum (1925–35) for each of these months is below 40°F. and it was considered that any effect would be most marked then. Similar data are available for East Malling and the deviations for this station were also computed. The differences between these deviations (Wye *minus* East Malling) were tabulated for the two 10-year periods 1925–34 and 1935–44. The frequency of positive values of these differences in each month is given below.

	November	December	January	February	March	April
1925–34	4	6	4	5	3	4
1935–44	6	8	8	7	8	9

These values suggest an increase in the minima at Wye after 1934 and a *t*-test was applied to the differences to determine whether the mean value was significantly different in the two periods. This test is described by R. A. Fisher*. It showed that the mean daily minimum at Wye over the months November to April was increased by nearly 0.4°F. after the glasshouses were erected, and the difference was significant at the 0.01 level.

Winds from between NE. and SE. blow over the glasshouses before reaching the screen. To determine whether the effect was related to wind direction, the correlation coefficient was calculated between the differences (Wye *minus* East Malling) and the monthly frequency of winds from these directions. This coefficient is only about .10 and is not significant. This is hardly surprising as the screen may be heated by radiation from the glasshouse. Also convective heating of the air near the screen may be just as great with westerly as with easterly winds because of the eddies set up by the glasshouse.

Possibly a similar effect occurs in screens near houses with central heating.

W. H. HOGG

University College, London, Meteorological Society

A meteorological society has been formed in University College, London, around a nucleus of staff and students who were formerly members of the Meteorological Office. Functions already held include a visit to the Central Forecasting Office and a lecture by Mr. P. J. Meade on recent changes in meteorological practice.

Anyone connected with the University of London who is interested in attending future meetings of the Society is invited to communicate with “The Secretary, Meteorological Society, University College, London Union, Gower Street, London, W.C.1.”

*FISHER, R. A. : Statistical methods for research workers. London; 10th edn., 1946, p. 122.

NEWS IN BRIEF

The L.G. Groves Memorial Prize for Meteorology has been awarded this year to Mr. C. S. Durst, B.A., Senior Principal Scientific Officer in the Meteorological Office, for successfully carrying out many important investigations into meteorological problems affecting the safety and efficient performance of Royal Air Force aircraft. During the past year Mr. Durst has produced seven important papers relating to wind at high levels over the whole globe. His work displays an exceptional ability in applying sound scientific methods to his problems, and in presenting the results in an essentially practical form.

The L. G. Groves Memorial Award for Meteorological Air Observers has been won this year by Sergeant R. T. D. Scott, R.A.F., for his zealous work as Meteorological Air Observer, No. 224 Squadron, Gibraltar, which has earned the highest praise. Sergeant Scott has maintained a standard of observational accuracy to a high order, and by his efforts has made a valuable contribution to the technical efficiency of the meteorological reconnaissance flights.

OBITUARY

Professor Antonino Lo Surdo.—We regret to report the death in Rome on June 7, 1949, of Professor A. Lo Surdo, aged 69 years, Founder and Director of the Italian National Institute of Geophysics and of the associated journal *Annali di Geofisica*. He was also Director of the Physical Institute of the University of Rome.

Professor Lo Surdo carried out important researches in several branches of geophysics, notably in seismology and the question of the effective radiating temperature of the sky. He worked also in other branches of physics, and was the discoverer of the splitting of spectral lines by an electric field (Lo Surdo and Stark effect).

WEATHER OF SEPTEMBER, 1949

Mean pressure was above 1015 mb. over most of Europe and over the United States (except the south-west) as well as over the North Atlantic from about 50°N. to at least 30°N. It was above 1020 mb. over the Azores and for a considerable distance westward of the Azores, also from southern Sweden and the Baltic to Austria, Hungary and Rumania. Regions with the mean appreciably below 1010 mb. were to be found only in Alaska and Spitzbergen.

Mean pressure was above normal over most of Europe, most of the northern part of the North Atlantic and the Mediterranean, the excess being from 5 to 8 mb. over Scandinavia and the Baltic. In North America deviations from normal were small.

The weather over the British Isles was characterised by exceptional warmth. At a number of stations with long records it was the warmest September on record, for example, at Oxford since 1815, at Kew Observatory since 1871. At Southport it was the warmest September since their record warm September in 1895. The nights, in particular, were exceedingly warm. The month was dry on the whole, apart from heavy local falls of thundery rain, sunnier than the average in most places and somewhat quieter than usual, particularly in northern districts.

During the first six days of the month a depression was situated north-west or west of the British Isles and troughs of low pressure or secondary depressions swung round it across the British Isles. Warm weather prevailed and rain fell at times in most areas, but the amounts were variable, while sunshine records were moderately good. High day temperatures were registered, particularly

on the 4th and 5th, among the highest readings being 91°F. at Maldon and 90°F. at Shoeburyness, Cromer, Belstead and Mildenhall on the 5th. The night of the 4th–5th was exceptionally warm; the minimum temperature on the 5th was 69°F. at Oxford and 67°F. at Kew, both record high minima for September. There were scattered thunderstorms during this period, the storms being widespread on the 4th and 5th. Thereafter from the 7th to 9th a belt of high pressure extended from the anticyclone north of the Azores across southern England and France, while small depressions moved north-east across our northern seaboard; some rain fell in the west and north. On the 10th and 11th a trough associated with a depression centred to the north moved very slowly south-east across the British Isles; rain, mainly slight, fell locally in Ireland and Scotland on the 10th but it was fair generally on the 11th. On the 12th an anticyclone north of Scotland moved east, while a trough of low pressure off our south-west coasts moving north-east gave rain later in the extreme south-west. This trough subsequently moved north across the country, causing heavy rain locally in the south of England on the 13th and in south and east Britain on the 14th. On the 15th another small secondary depression over Cornwall moved north-east; rain fell in most places on the 15th and locally, chiefly in the north, on the 16th.

Subsequently a wedge of high pressure moved in over the British Isles and, thereafter, until the 21st, pressure was high in a belt extending across Scotland to Norway. Meanwhile a trough to a depression off our south-west coasts extended from south-west Ireland to north France, where it remained almost stationary for several days; heavy rain occurred in south-west England on the 20th and 21st, over 2 in. being registered at stations in Cornwall on the 20th and at numerous places in Dorset on the 21st (2·44 in. at West Looe on the 20th and 2·79 in. at Creech Grange on the 21st). Subsequently the trough moved slowly north on the 22nd and 23rd, giving rain and local thunderstorms, particularly in England, Wales and east Scotland. More than 2 in. was recorded at a number of places in the southern half of England and Wales on the 22nd, for example 2·96 in. at Presteign, Radnor, of which roughly 2¾ in. fell in 80 minutes, 2·66 in. at Chipping Norton, Oxon, and 2·59 in. at Bridgend, Glam. On the 24th a new depression south of Iceland moved south-south-east; rain fell in England and Wales, Ireland and south Scotland, with local thunderstorms but the rainfall was not generally very heavy.

Thereafter conditions were mainly anticyclonic; from the 25th–29th a large anticyclone over central Europe maintained fair weather, apart from mist or fog, over most of the British Isles, and on the last day a ridge associated with an anticyclone in mid Atlantic extended over this country.

The general character of the weather is shown by the following provisional figures :—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	91	36	+5·4	80	-4	105	39
Scotland ..	80	26	+4·0	74	-4	110	33
Northern Ireland ..	73	36	+3·9	90	-5	121	38

RAINFALL OF SEPTEMBER 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ..	·36	20	<i>Glam.</i>	Cardiff, Penylan ..	3·65	120
<i>Kent</i>	Folkestone, Cherry Gdn.	3·08	130	<i>Pemb.</i>	St. Ann's Head ..	1·11	39
<i>"</i>	Edenbridge, Falconhurst	·92	41	<i>Card.</i>	Aberystwyth ..	2·10	74
<i>Sussex</i>	Compton, Compton Ho.	2·71	97	<i>Radnor</i>	Tyrmynydd ..	2·69	70
<i>"</i>	Worthing, Beach Ho.Pk.	1·69	79	<i>Mont.</i>	Lake Vyrnwy ..	1·74	46
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	3·75	151	<i>Mer.</i>	Blaenau Festiniog ..	2·57	33
<i>"</i>	Bournemouth ..	4·44	190	<i>Carn.</i>	Llandudno ..	·56	26
<i>"</i>	Sherborne St. John ..	2·51	122	<i>Angl.</i>	Llanerchymedd ..	2·01	68
<i>Herts.</i>	Royston, Therfield Rec.	·43	23	<i>I. Man.</i>	Douglas, Borough Cem.	2·27	69
<i>Bucks.</i>	Slough, Upton ..	·87	49	<i>Wigtown</i>	Port William, Monreith	2·38	82
<i>Oxford</i>	Oxford, Radcliffe ..	2·29	134	<i>Dumf.</i>	Dumfries, Crichton R.I.	1·91	70
<i>N'hant.</i>	Wellingboro', Swanspool	1·29	72	<i>"</i>	Eskdalemuir Obsy. ..	2·69	73
<i>Essex</i>	Shoeburyness ..	1·45	84	<i>Roxb.</i>	Kelso, Floors ..	1·26	66
<i>Suffolk</i>	Campsea Ashe, High Ho.	1·56	82	<i>Peebles</i>	Stobo Castle ..	1·98	79
<i>"</i>	Lowestoft Sec. School ..	1·87	95	<i>Berwick</i>	Marchmont House ..	1·49	62
<i>"</i>	Bury St. Ed., Westley H.	1·01	51	<i>E. Loth.</i>	North Berwick Res. ..	·95	45
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·35	65	<i>Mid'n.</i>	Edinburgh, Blackf'd. H.	1·75	85
<i>Wilts.</i>	Bishops Cannings ..	1·07	49	<i>Lanark</i>	Hamilton W. W., T'nhill	1·29	48
<i>Dorset</i>	Creech Grange ..	7·30	266	<i>Ayr</i>	Colmonell, Knockdolian	2·86	82
<i>"</i>	Beaminster, East St. ..	4·74	186	<i>"</i>	Glen Afton, Ayr San ..	2·37	61
<i>Devon</i>	Teignmouth, Den Gdns.	2·75	140	<i>Bute</i>	Rothsay, Arden Craig	2·56	63
<i>"</i>	Cullompton ..	4·93	219	<i>Argyll</i>	L. Sunart, Glenborrodale	3·00	48
<i>"</i>	Barnstaple, N. Dev. Ath.	1·90	70	<i>"</i>	Poltalloch ..	2·39	52
<i>"</i>	Okehampton, Uplands	3·28	101	<i>"</i>	Inveraray Castle ..	4·14	64
<i>Cornwall</i>	Bude, School House ..	3·96	160	<i>"</i>	Islay, Eallabus ..	3·77	90
<i>"</i>	Penzance, Morrab Gdns.	2·20	75	<i>"</i>	Tiree ..	3·44	93
<i>"</i>	St. Austell, Trevarna ..	4·70	147	<i>Kinross</i>	Loch Leven Sluice ..	2·71	105
<i>"</i>	Scilly, Tresco Abbey ..	4·63	181	<i>Fife</i>	Leuchars Airfield ..	1·59	82
<i>Glos.</i>	Cirencester ..	1·46	66	<i>Perth</i>	Loch Dhu ..	3·55	62
<i>Salop.</i>	Church Stretton ..	1·89	90	<i>"</i>	Crieff, Strathearn Hyd.	1·17	41
<i>"</i>	Cheswardine Hall ..	·65	32	<i>Perth</i>	Pitlochry, Fincastle ..	1·19	47
<i>Worcs.</i>	Malvern, Free Library	1·64	85	<i>Angus</i>	Montrose, Sunnyside ..	1·87	94
<i>Warwick</i>	Birmingham, Edgbaston	1·11	62	<i>Aberd.</i>	Braemar ..	1·75	70
<i>Leics.</i>	Thornton Reservoir ..	1·67	92	<i>"</i>	Dyce, Craibstone ..	1·91	79
<i>Lincs.</i>	Boston, Skirbeck ..	1·65	94	<i>"</i>	Fyvie Castle ..	1·36	52
<i>"</i>	Skegness, Marine Gdns.	1·25	69	<i>Moray</i>	Gordon Castle ..	2·47	99
<i>Notts.</i>	Mansfield, Carr Bank ..	1·02	55	<i>Nairn</i>	Nairn, Achareidh ..	1·01	48
<i>Derby</i>	Buxton, Terrace Slopes	1·48	46	<i>Inv's</i>	Loch Ness, Foyers ..	1·53	52
<i>Ches.</i>	Bidston Observatory ..	·85	35	<i>"</i>	Glenquoich ..	·	·
<i>Lancs.</i>	Manchester, Whit. Park	·56	24	<i>"</i>	Fort William, Teviot ..	4·94	77
<i>"</i>	Stonyhurst College ..	1·86	49	<i>"</i>	Skye, Duntuilum ..	4·39	95
<i>"</i>	Blackpool ..	·84	29	<i>R. & C.</i>	Ullapool ..	2·75	76
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·26	79	<i>"</i>	Applecross Gardens ..	5·15	103
<i>"</i>	Hull, Pearson Park ..	1·12	65	<i>"</i>	Achnashellach ..	6·69	97
<i>"</i>	Felixkirk, Mt. St. John	·49	27	<i>"</i>	Stornoway Airfield ..	3·42	91
<i>"</i>	York Museum ..	·80	49	<i>Suth.</i>	Lairg ..	·	·
<i>"</i>	Scarborough ..	·93	52	<i>"</i>	Loch More, Achfary ..	6·95	121
<i>"</i>	Middlesbrough ..	·60	36	<i>Caith.</i>	Wick Airfield ..	2·38	95
<i>"</i>	Baldersdale, Hury Res.	1·94	78	<i>Shetland</i>	Lerwick Observatory ..	2·79	93
<i>Nor'l'd.</i>	Newcastle, Leazes Pk. ..	·72	36	<i>Ferm.</i>	Crom Castle ..	2·23	80
<i>"</i>	Bellingham, High Green	1·93	80	<i>Armagh</i>	Armagh Observatory ..	2·47	100
<i>"</i>	Lilburn Tower Gdns. ..	2·04	86	<i>Down</i>	Seaforde ..	2·96	108
<i>Cumb.</i>	Geltsdale ..	1·21	43	<i>Antrim</i>	Aldergrove Airfield ..	1·93	78
<i>"</i>	Keswick, High Hill ..	2·07	49	<i>"</i>	Ballymena, Harryville ..	2·48	80
<i>"</i>	Ravenglass, The Grove	2·60	77	<i>L'derry</i>	Garvagh, Moneydig ..	3·12	105
<i>Mon.</i>	Abergavenny, Larchfield	3·21	137	<i>"</i>	Londonderry, Creggan	2·34	71
<i>Glam.</i>	Ystalyfera, Wern House	2·75	63	<i>Tyrone</i>	Omagh, Edenfel ..	3·07	101

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, MAY 1949

STATIONS	PRESSURE		TEMPERATURES							REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION		BRIGHT SUNSHINE			
	Mean of day M.S.L.	Diff. from normal	Absolute		Mean values							Total	Diff. from normal	Days	Daily mean	Per- centage of possible	
			Max.	Min.	°F.	°F.	°F.	°F.	°F.								°F.
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	oktas	in.	in.	hr.	%		
1015.3	+0.3	69	35	45.1	53.4	61.7	48.1	-1.3	48.1	70	5.2	2.30	+0.58	12	45		
Gibraltar ..	1014.8	-1.3	81	52	59.1	73.3	66.2	+0.7	60.5	70	4.0	0.34	—	11	72		
Malta ..	1012.8	-1.7	80	55	59.6	73.0	66.3	+0.4	62.6	66	3.7	0.52	—	4	71		
St. Helena ..	1016.0	-0.9	75	57	59.9	70.2	65.1	+2.5	59.8	94	6.1	5.34	+2.80	17	—		
Lungi, Sierra Leone	1011.9	—	91	73	76.7	88.2	82.5	—	76.3	78	5.9	5.07	—	11	54		
Lagos, Nigeria	1011.1	+0.5	95	70	73.5	90.5	82.0	+0.2	78.4	79	6.6	7.36	—	14	51		
Kaduna, Nigeria ..	1008.3	—	95	65	71.3	88.6	79.9	0.0	74.1	80	6.3	4.11	-1.59	13	62		
Chileka, Nyasaland	1019.0	-0.1	88	55	61.2	77.9	69.5	+1.5	62.2	71	3.6	0.60	+0.30	7	55		
Lusaka, Rhodesia ..	1017.1	0.0	86	48	55.4	78.9	67.1	+2.0	58.0	70	2.9	0.51	+0.46	1	77		
Salisbury, Rhodesia	1019.2	-0.2	83	41	50.5	73.5	62.0	+0.9	54.3	70	2.7	0.90	+0.52	5	65		
Cape Town ..	1018.0	-0.1	92	39	59.0	70.2	60.1	+1.2	49.9	74	4.5	1.63	-2.12	18	—		
Palmfontein, S. Africa	1024.6	—	75	31	38.0	67.9	52.9	—	42.9	73	1.0	0.05	—	2	—		
Mauritius	1004.0	+0.4	102	69	77.6	92.2	84.9	-1.2	79.3	77	5.1	10.32	+4.76	16	62		
Calcutta, Alipore Obys.	1005.3	-2.1	94	76	80.5	92.2	86.3	+0.5	78.5	74	4.7	0.98	+0.43	6	69		
Bombay ..	1005.0	-0.4	105	75	81.1	96.5	88.8	-1.0	77.7	66	4.7	7.95	+6.11	5	63		
Madras	1008.7	+0.3	90	73	76.8	87.0	81.9	-0.9	77.6	83	6.1	12.62	+1.48	20	52		
Colombo, Ceylon ..	1008.7	0.0	90	73	75.6	87.5	81.5	-0.5	77.3	83	5.4	8.88	+2.24	17	—		
Singapore ..	1010.5	+1.4	89	69	75.2	83.6	79.4	+2.0	74.7	82	—	4.57	+7.50	10	40		
Hongkong ..	1020.6	+2.0	77	43	52.5	66.7	59.6	+0.8	53.8	80	5.3	4.01	-1.17	14	56		
Sydney, N.S.W. ..	1020.9	+1.7	72	32	45.2	59.6	52.4	-1.7	48.1	79	5.6	2.51	+0.35	16	32		
Melbourne ..	1022.2	+2.0	72	42	48.8	63.2	56.0	-2.0	51.0	67	6.0	2.55	-0.67	14	40		
Adelaide ..	1021.4	+3.0	84	43	51.7	70.7	61.2	+0.5	56.0	65	3.0	0.77	-4.20	6	71		
Perth, W. Australia	1022.5	+3.4	84	37	46.0	68.3	57.1	-0.6	49.7	64	2.9	0.30	-1.03	4	—		
Coolgardie ..	1019.6	+1.0	80	45	54.2	72.8	63.5	-1.1	57.1	65	3.4	1.68	-1.13	9	69		
Brisbane ..	1019.9	+4.6	75	33	43.5	56.1	49.8	-0.7	44.7	73	6.5	2.10	+0.50	18	32		
Hobart, Tasmania	1023.0	+7.7	65	26	46.3	57.1	51.7	+0.3	48.7	84	5.9	3.19	-1.49	12	41		
Wellington, N.Z. ..	1013.1	+0.4	87	69	72.7	80.8	76.7	+0.2	73.9	86	6.8	36.13	+26.06	26	22		
Suva, Fiji ..	1011.0	+0.3	89	71	73.9	86.6	80.3	+0.6	76.9	79	4.8	11.57	+5.04	20	62		
Apia, Samoa ..	1013.5	+0.4	89	70	72.9	87.7	80.3	+0.6	74.7	75	4.0	3.35	-1.04	8	61		
Kingston, Jamaica	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Grenada, W. Indies	1016.3	+1.4	90	71	74.0	87.0	80.5	+0.8	77.0	83	5.0	2.88	-1.31	11	—		
Toronto ..	1014.5	+0.7	84	37	47.1	69.0	58.1	+4.3	46.8	65	5.0	0.41	-0.28	7	61		
Winnipeg ..	1015.6	+1.7	76	35	41.8	65.7	52.9	+0.9	41.7	77	7.5	1.71	-0.29	9	43		
St. John, N.B. ..	1015.8	-0.9	74	33	45.0	64.4	48.9	+1.2	44.6	79	7.6	3.63	-0.08	13	48		
Victoria, B.C. ..	—	—	—	—	—	—	—	+1.7	45.3	86	4.3	0.71	-0.42	7	67		

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HUMIDITY OF THE LOWER STRATOSPHERE

The Results of High-Level Ascents by Aircraft of the Meteorological Research Flight

By H. C. SHELLARD, B.Sc.

Introduction.—The results of over 70 high-level ascents made by aircraft of the Meteorological Research Flight provide data from which mean values of humidity in the upper troposphere and lower stratosphere are obtained. Mean lapse rates of frost point and temperature in the neighbourhood of the tropopause are discussed. Significant correlations are shown to exist between frost point at levels between 200 and 300 mb., height of tropopause, and temperature at 500 mb.

Available data and their treatment.—The ascents dealt with have been made at various times during the past 6 years, and include Fortress and Mosquito ascents from Boscombe Down (1943-45) as well as more recent Mosquito ascents from Farnborough, the majority of which have been made in 1949. The data consist of measurements of temperature and frost point, usually at 1,000-ft. intervals, temperatures being measured by M.O. knife-type resistance thermometers with balanced-bridge indicators, and frost points by one of the M.O. aircraft frost-point hygrometers.

The ceiling of the Mosquito aircraft employed varies between 38,000 and 41,000 ft., whilst that of the Fortress used for the ascents of 1943-44 varied from 33,000 to 37,000 ft.; nearly three-quarters of the ascents, however, reached or exceeded the 200-mb. level (38,500 ft.).

Of the 77 ascents available, ten failed to reach the tropopause, two gave doubtful results (of these more will be said later), and one consisted of such limited data that the position of the tropopause could not be fixed satisfactorily. For each of the remaining 64 ascents, the first step was to decide the tropopause height and type. It was found that the current Meteorological Office definitions as given in *S.D.T.M.* 107¹* and in the Introduction to the *Upper Air Section of the Daily Weather Report* (the two differ slightly) were not sufficiently precise, and the following amended definitions were therefore adopted :—

*These numbers refer to the list of references on p. 349.

Type I.—There is an abrupt change of lapse rate to inversion, and for no subsequent 3,280-ft. (1-Km.) layer does the lapse rate exceed $1.1^{\circ}\text{F./1,000 ft.}$ (2°C./Km.). H_c is the height of the abrupt change.

Type II.—There is an abrupt change to a lapse rate of less than $1.1^{\circ}\text{F./1,000 ft.}$ (2°C./Km.), or to isothermal, and for no subsequent 3,280 ft. (1 Km.) does the lapse rate exceed $1.1^{\circ}\text{F./1,000 ft.}$ (2°C./Km.). H_c is the height of the abrupt change.

Type III.—Where there is no abrupt change of lapse rate H_c is taken as the height of the point at which the lapse rate first becomes less than $1.1^{\circ}\text{F./1,000 ft.}$ (2°C./Km.), provided that it does not exceed this value for any subsequent 3,280-ft. (1-Km.) layer.

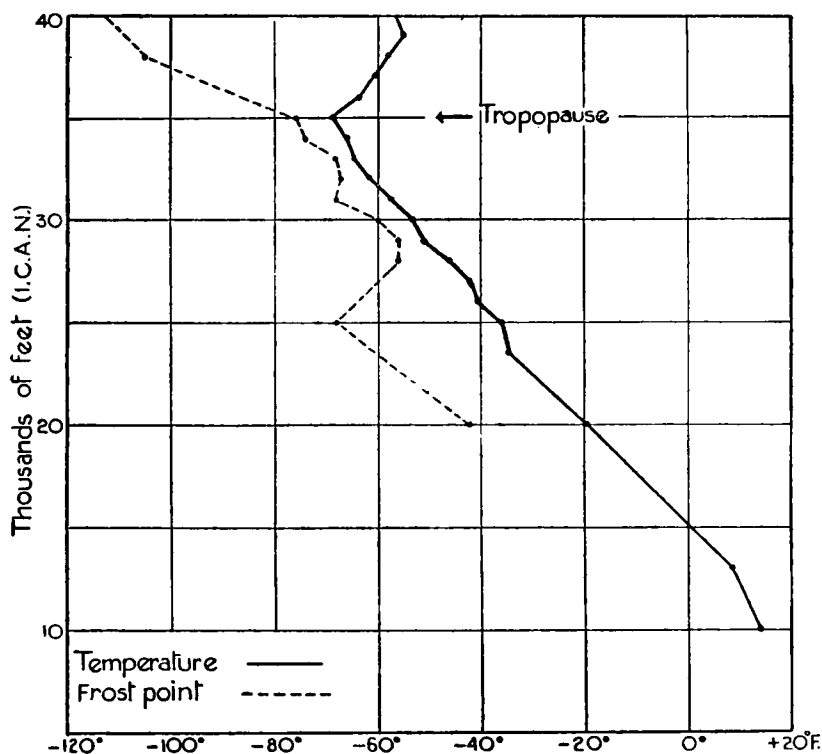


FIG. 1—AIRCRAFT SOUNDING, 1500 G.M.T., MAY 24, 1948

In addition the following rules have been adopted :—

(a) An abrupt change is defined as one in which the mean lapse rates measured over 1,000-ft. layers on either side of the change differ by at least $2^{\circ}\text{F./1,000 ft.}$

(b) Where there is a double tropopause, *i.e.* two abrupt changes as defined in (a), the lower one satisfying the Type II tropopause definition and the upper one the Type I definition given above, then in this paper the tropopause is taken as being at the lower level and is classified as Type II.

Having fixed the tropopause pressure (P_c), values of temperature and frost point were extracted from each ascent, (i) for the levels ($P_c + 150$)mb. to ($P_c - 100$)mb. at 25-mb. intervals, *i.e.* for levels relative to the tropopause as origin, and (ii) for the fixed pressure levels 200, 250 and 300 mb. These

values were tabulated so that means could be readily computed and values of relative humidity obtained as required. Correlation coefficients between the various quantities were also evaluated.

The mean tropopause height given by the ascents considered is about 34,000 ft., whilst that given by radio-sonde ascents for south England is about 36,000 ft. Thus there is some bias towards low tropopause in our ascents.

Discussion.—General.—Table I is a frequency table of relative humidity with respect to ice, which conveniently summarises the observations. The outstanding features are (i) the rapid decrease in relative humidity as the stratosphere is entered, and (ii) the fact that the relative humidity continues to decrease, though less rapidly, the further into the stratosphere one goes. Mean values are given for each level. Eight of the ascents penetrated 100 mb. into the stratosphere, the mean relative humidity at that level being 2.2 per cent. and the range 0.9 to 3.9 per cent.

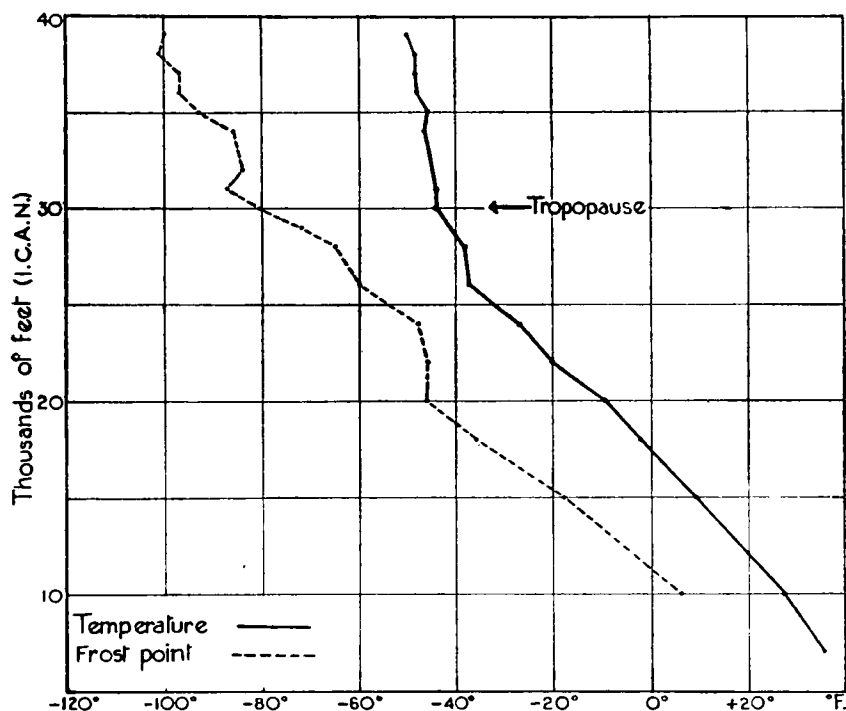


FIG. 2—AIRCRAFT SOUNDING, 0930 G.M.T., JULY 5, 1949

On examining individual ascents perhaps the first thing which strikes one is that there is often a sharp fall of frost point on entering the stratosphere. This was remarked upon by Dobson, Brewer and Cwilog² in their discussion of some of the early Boscombe Down ascents. This rapid fall of frost point does not always occur, however, and there are many ascents in which the frost-point lapse rate is not materially different above and below the tropopause. Typical examples of ascents of the two types are given in Figs. 1 and 2.

Further examination reveals that ascents showing this frost-point lapse discontinuity at the tropopause more often than not have Type I tropopause, whilst those showing little or no such discontinuity more often than not have Type II tropopause. On some of the first type the sharp frost-point fall does

TABLE 1—FREQUENCY OF RELATIVE HUMIDITY (WITH RESPECT TO ICE)

Relative humidity range % Level	0-0.9	1-2.9	3-4.9	5-9.9	10-14	15-19	20-24	25-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100 >	Mean relative humidity	Total No. of cases
50 mb. below tropopause	0	0	0	3	1	3	5	5	13	9	6	7	5	1	2	0	43.5	60
25 mb. below tropopause	0	1	0	2	5	3	4	1	12	7	11	6	3	2	2	1	44.2	60
Tropopause	0	1	1	7	3	1	4	2	14	10	6	4	6	1	3	1	42.5	64
25 mb. above tropopause	0	4	6	13	8	10	8	4	..	..	..	..	..	..	..	..	13.8	58
50 mb. above tropopause	0	16	9	7	2	2	1	..	..	..	..	..	..	..	..	..	5.3	37
75 mb. above tropopause	2	14	2	3	..	..	..	..	..	..	..	..	..	..	..	..	2.7	21
100 mb. above tropopause	1	5	2	..	..	..	..	..	..	..	..	..	..	..	..	..	2.2	8

not always coincide with the tropopause ; it may be a little higher or lower. Thus it would be impracticable to replace the existing official definitions of the tropopause, based on temperature lapse-rate changes, by a set of definitions based on frost-point lapse-rate changes.

In the stratosphere frost points nearly always lie within the range -80° to -120°F . Two exceptional ascents (mentioned earlier) made on successive days, January 19 and 20, 1948, indicated moist conditions in the stratosphere, however. The first gave a frost point of -72°F . (relative humidity 26 per cent.) and the second one of -62°F . (relative humidity 75 per cent.) at the 200-mb. level, which in each case was well into the stratosphere. For the present we have rejected these two ascents, (i) because the results are completely at variance with all others we have obtained, and (ii) because when, as in this case, observations are made with the Mk.2a hygrometer in a pressurised cabin, there is always the chance of moist cabin air leaking into the instrument. Nevertheless the possibility remains that very occasionally the air in the lower stratosphere may be nearly saturated.

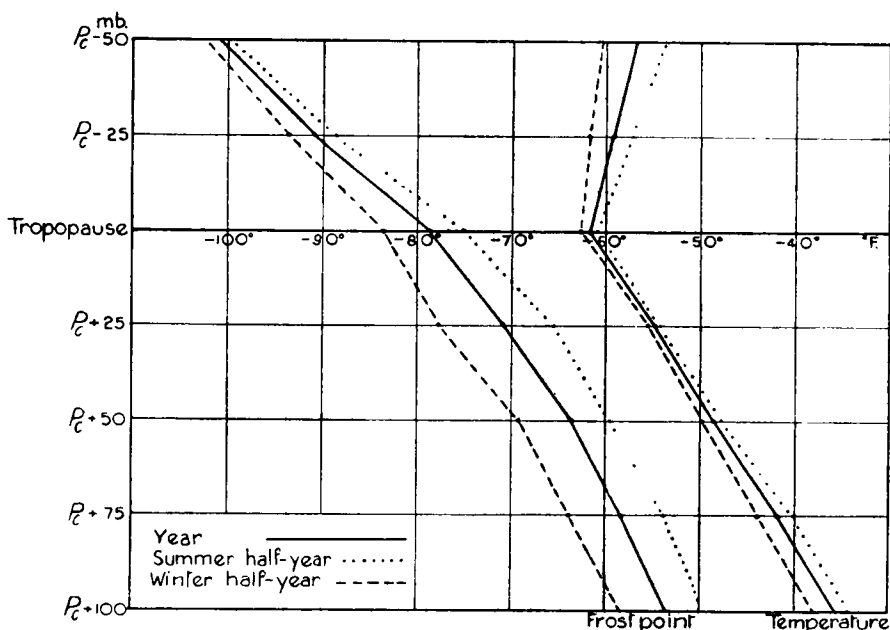


FIG. 3—MEAN CURVES FOR SELECTED ASCENTS SHOWING SEASONAL VARIATION

Year, 32 ascents, mean $P_c = 272$ mb.
 Summer half-year, 18 ascents, mean $P_c = 265$ mb.
 Winter half-year, 14 ascents, mean $P_c = 281$ mb.

Mean ascent curves.—Of our 64 ascents only 32 provide complete frost-point and temperature data between the levels ($P_c + 100$)mb. to ($P_c - 50$)mb., chiefly because of the limited aircraft ceiling. To obtain representative mean ascent curves penetrating the stratosphere by 50 mb. (approximately 5,000 ft. at this level), it is necessary therefore to mean the results of these 32 ascents only. Fig. 3 shows the mean curves so obtained, and also similar curves for the 14 ascents made during the winter half-year, and for the 18 ascents made during the summer half-year. Because the mean tropopause pressure over south England is at a maximum in mid February and a minimum in mid August, the winter half-year was taken as mid November to mid May and the summer half-year as mid May to mid November.

The curves of Fig. 3 indicate that there is little seasonal variation in the moisture content of the lower stratosphere. Frost points not far above the tropopause tend to be higher in summer, but further into the stratosphere the difference decreases. On the curve for the full year the average frost-point lapse is 7.9°F. in the 25-mb. layer below the tropopause. In the stratosphere the frost point falls 12.2°F. in the first and 10.0°F. in the second 25-mb. layer. The rate of fall of frost point in the stratosphere is greater than in the upper troposphere and decreases with height. It may be that the frost point in the stratosphere eventually becomes constant, though the curves of Fig. 3 do not extend sufficiently far upwards to show whether this is so or not. More ascents on occasions of low tropopause, or preferably, ascents to greater altitudes than 40,000 ft. are required.

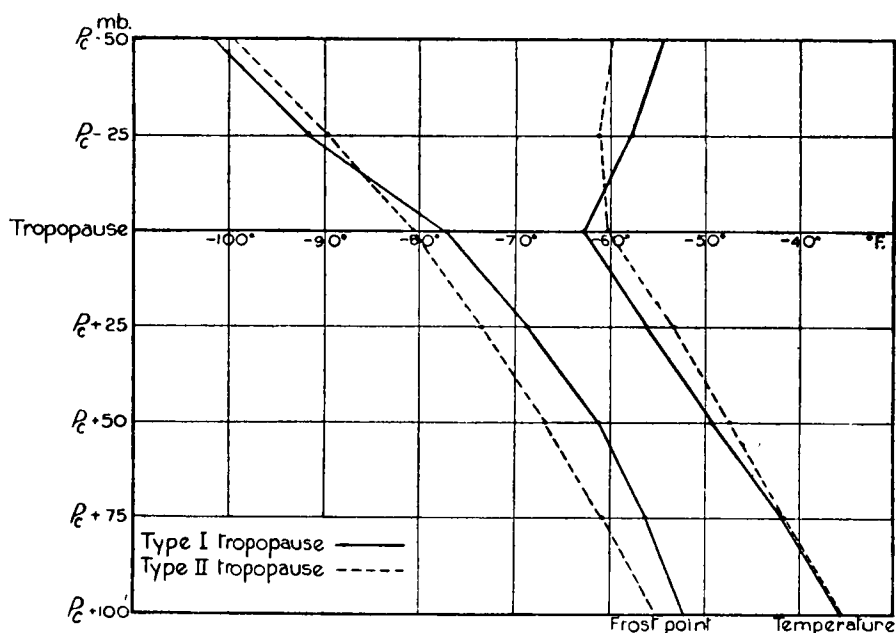


FIG. 4—MEAN CURVES FOR SELECTED ASCENTS, GROUPED
ACCORDING TO TYPE OF TROPOPAUSE

Type I tropopause, 18 ascents, mean $P_c = 270$ mb.

Type II tropopause, 14 ascents, mean $P_c = 274$ mb.

Fig. 4 shows mean ascent curves for the 32 ascents when grouped according to type of tropopause. For Type I tropopause the frost point falls in the 25-mb. layer below and above the tropopause are 8.5° and 14.3°F. respectively (a difference of 5.8°F.), whilst for Type II the corresponding figures are 7.2° and 9.1°F. (a difference of only 1.9°F.). This clearly indicates the tendency for a steep frost-point lapse rate just above the tropopause to be associated with temperature inversion. On the other hand the discontinuity in frost-point lapse rate is quite small when there is no temperature inversion (Type II tropopause). It may well be that this steepening of frost-point lapse rate is not specially a characteristic of the tropopause, but that it occurs only because there is a temperature inversion, for it is well known that the same effect occurs at subsidence inversions in the troposphere.

Some correlation coefficients.—The results discussed above suggest a correlation between lapse rate of temperature and lapse rate of frost point in the lower-stratosphere. Values of temperature and of frost-point fall in the layer 25-mb.

thick above the tropopause were therefore correlated. Considering all ascents a coefficient of -0.41 from 58 pairs of values was obtained, whilst for ascents with Type I tropopause only the coefficient was -0.61 from 35 pairs of values. The probabilities of such correlations arising by random sampling from an uncorrelated population are in both cases less than one in one hundred.

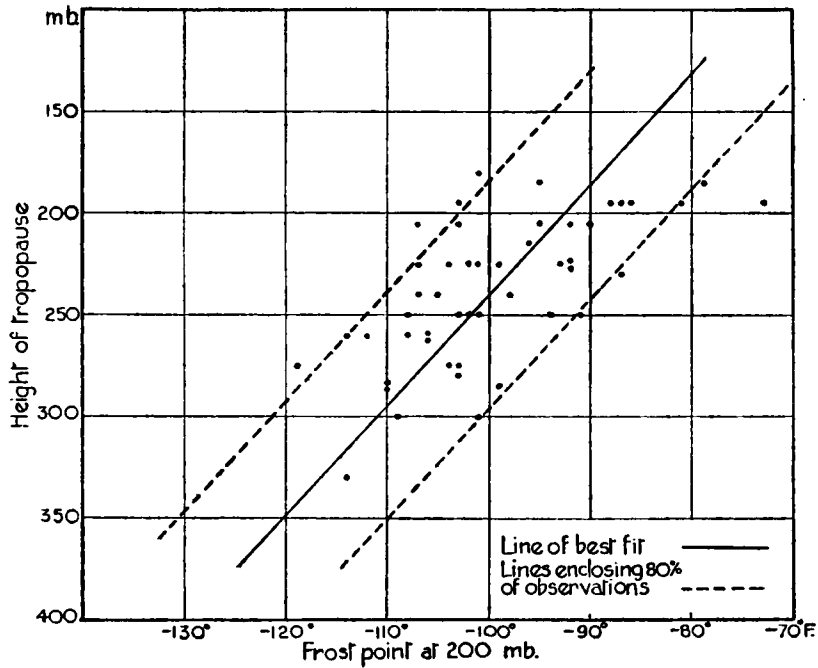


FIG. 5—RELATION BETWEEN TROPOPAUSE HEIGHT AND FROST POINT AT THE 200-MB. LEVEL

A number of other quantities have been correlated with the results set out in Table II below, where (xy) is the correlation coefficient between any variables x and y , P_c , F_c and T_c are the pressure, frost point and temperature at the tropopause respectively. F_{50} the frost point 50 mb. above the tropopause F_{200} , F_{250} and F_{300} the frost points at 200, 250 and 300 mb. respectively and T_{500} the temperature at 500 mb.

TABLE II—SOME CORRELATION COEFFICIENTS

	Correlation coefficient	No. of pairs of values		Correlation coefficient	No. of pairs of values
$(P_c F_c)$	$+0.50$	64	$(P_c T_c)$	$+0.81$	64
$(P_c F_{50})$	$+0.42$	37	$(P_c T_{500})$	-0.61	64
$(P_c F_{200})$	-0.67	48	$(T_{500} F_{200})$	$+0.62$	48
$(P_c F_{250})$	-0.67	63	$(T_{500} F_{250})$	$+0.82$	63
$(P_c F_{300})$	-0.62	64	$(T_{500} F_{300})$	$+0.79$	64

The correlation $(P_c T_c)$ represents a well known fact, the higher the tropopause the colder it is. The correlation between P_c and frost point at the tropopause, F_c , is moderately significant, but that between P_c and the frost point 50 mb. above the tropopause (a level chosen as representative of the stratospheric air) is definitely less so. The three correlations between P_c and the frost points at 200, 250 and 300 mb. are very significant, and these relationships are illustrated as dot diagrams in Figs. 5 and 6 respectively. In each case the full lines are

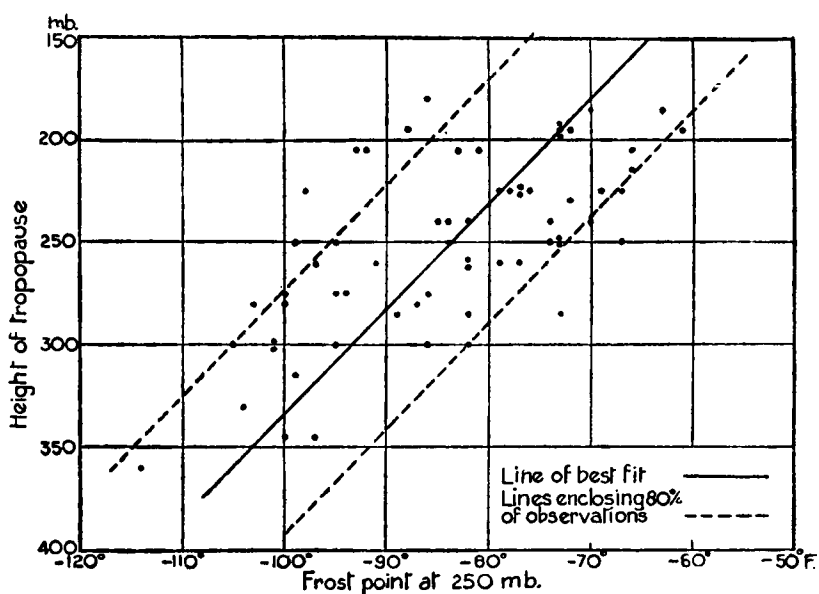


FIG. 6—RELATION BETWEEN TROPOPAUSE HEIGHT AND FROST POINT AT THE 250-MB. LEVEL

lines of best fit whilst the parallel dashed lines enclose 80 per cent. of the observations. They indicate that, given P_c , F_{200} and F_{250} can be predicted to within 10° and $11\frac{1}{2}^\circ\text{F}$. respectively on 80 per cent. of occasions. Alternatively, given F_{200} or F_{250} , P_c can be predicted to within 54 or 59 mb. on 80 per cent. of occasions.

The correlations between F_{200} , F_{250} and F_{300} , and P_c are similar in magnitude to those found by Dines (0.7 approx.) and Priestley (0.65)¹ between T_{500} and

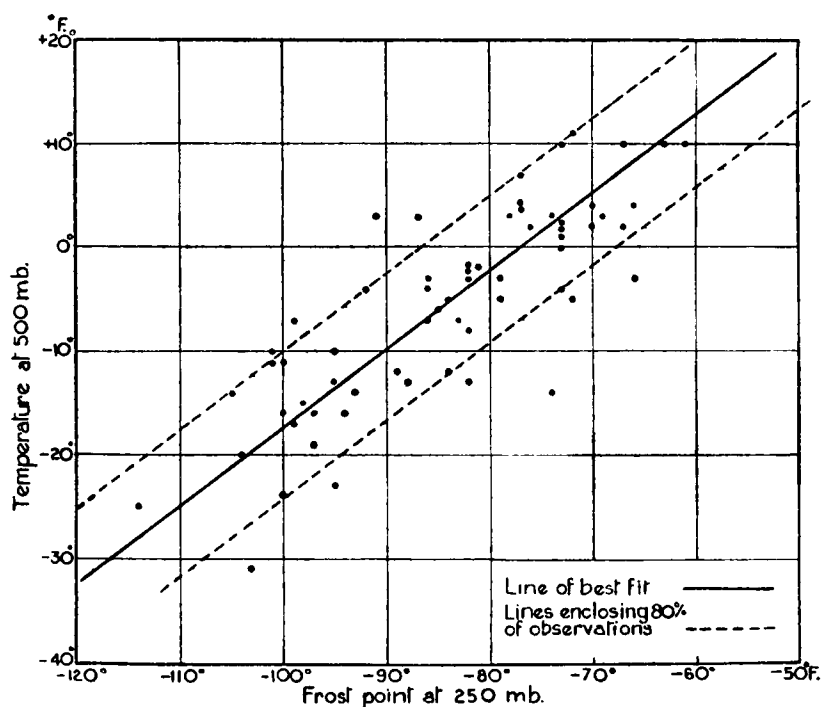


FIG. 7—RELATION BETWEEN TEMPERATURE AT 500 MB. AND FROST POINT AT 250 MB.

H_c , and it seems possible, therefore, that the frost point at a fixed level may be associated with the mean temperature of the troposphere through which the moisture may have ascended. Priestley has shown that T_{500} can be taken as representative of the whole column of air in the troposphere, and that it is in fact preferable to T_m (the mean temperature from 1000 to 300 mb.) for this purpose. Correlation coefficients were therefore computed between T_{500} and F_{200} , F_{250} and F_{300} . The last two are remarkably high, and the highest, that between T_{500} and F_{250} , is illustrated in Fig. 7 as a dot diagram. Here again the line of best fit and lines enclosing 80 per cent. of the observations have been drawn in. It follows that given T_{500} , F_{250} can be predicted to within $9\frac{1}{2}^{\circ}\text{F}$. on 80 per cent. of occasions. It may be significant that the correlation between frost point and T_{500} is least at 200 mb., a level which is predominantly stratospheric. This would suggest that the frost point in the stratosphere is less subject to control by tropospheric processes, or is less of an air-mass characteristic than is the frost point at lower (predominantly tropospheric) levels. Finally a coefficient of -0.61 between P_c and T_{500} was obtained for our observations, and this agrees well with Priestley's value of $+0.65$ between H_c and T_{500} .

Conclusions.—(1) Frost points in the lower stratosphere (up to 40,000 ft.) over south England are almost invariably low and within the range -80° to -120°F .

(2) There is some evidence, not yet conclusive, for a small seasonal variation in the moisture content of the lower stratosphere, frost points being higher in summer than in winter.

(3) There is often an increase in frost-point lapse rate at the tropopause. A rapid decrease in frost point above the tropopause is most likely to occur when the temperature lapse changes sharply to inversion, and there appears to be an inverse relation between frost-point lapse rate and temperature lapse rate in the lower stratosphere.

(4) Very significant correlations exist between P_c and the moisture content of the atmosphere between 300 and 200 mb., and also between T_{500} and the moisture content of this region. Whilst in the former case there is no very significant variation of the correlation coefficient with height between 300 and 200 mb., in the latter the correlation is definitely least at 200 mb. (a predominantly stratospheric level).

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A NOTE ON THE 1000-700-mb. THICKNESS AND THE HEIGHT OF THE FREEZING LEVEL OVER THE BRITISH ISLES

By R. MURRAY, M.A.

Introduction.—Synoptic experience shows that there is an intimate relationship between the thickness of the 1000-700-mb. layer and the height of the freezing level. From a sample of observations over the British Isles the cor-

relation has been worked out, with the practical end in view of making use of the 700-mb. prontours (the forecast 700-mb. upper air charts issued by the Central Forecasting Office) as a convenient and systematic method of forecasting the height of the freezing level. The use of this method is limited in practice to air which is commonly classed as "cold" or "polar", where the 1000-700-mb. thickness is less than 9,500 ft.

Data used.—The 0300 G.M.T. and 1500 G.M.T. British (including Valentia) upper air observations for January, August and April 1-5, 1948, were examined. On the whole, the weather was unsettled during these periods. Although there is some correspondence between the height of the freezing level and the 1000-700-mb. thickness in all cases, it was obvious from the data that the relationship was close enough to be useful in practice only when certain simple synoptic rejection criteria were applied to the ascents. An ascent was rejected from the analysis when (a) the 1000-700-mb. thickness was equal to or greater than 9,500 ft., (b) an approaching warm front or occlusion was within 400 miles, (c) a receding cold front (excluding minor or instability fronts in the cold air) or occlusion was within 200 miles, and (d) an anticyclonic centre (minor bubbles of high pressure being ignored) was within 400 miles of the station. No occasions of cold winter continental air were examined. With these provisos the types of air over the British Isles were varied, including very deep and rather shallow cold air. Altogether there were 268 ascents with the thickness of the layer 1000-700 mb. (t_7) less than 9,500 ft. If proviso (a) is relaxed, there were 72 ascents with t_7 equal to or greater than 9,500 ft.

Analysis of data.—There were some cases when the freezing-level point was not unique. In one type the surface air was below 32°F., due to nocturnal cooling, with the main freezing level above the ground inversion; in this case the representative freezing level was taken at the upper point and not at the surface. In the second type, which normally occurred with large values of t_7 , the cold air was generally rather shallow with the lowest freezing level at some thousand feet and a subsidence inversion above it, causing a more or less thin layer of air to be at temperatures above 32°F.; in this case the representative freezing point was taken at the lowest level.

In order to allow for different mean-sea-level pressures, the 1000-700-mb. thickness (t_7) was correlated with the height of the freezing level above the 1000-mb. surface (H_F) and not with the height of the freezing level above mean sea level. The results are as follows:—

Correlation coefficient = 0.945, with probable error 0.004;

$$H_F = 12.33/7 - 110,900 \text{ (regression equation);}$$

standard deviation in H_F for given t_7 equals 460 ft. (to nearest 10 ft.).

From the regression equation we obtain Table I. The regression equation may be put into useful graphical form also.

TABLE I

		<i>feet</i>									
t_7	..	9,000	9,050	9,100	9,150	9,200	9,250	9,300	9,350	9,400	9,450
H_F	..	100	700	1,300	1,900	2,500	3,200	3,800	4,400	5,000	5,600

Forecasting application.—The thickness of the 1000-700-mb. layer is not broadcast but can easily be obtained from the 700-mb. prontours and the prebaratics (the official forecast of mean-sea-level synoptic charts) which

include the positions of the main fronts and pressure centres as well as isobars, From these forecast charts we readily see whether or not the region of the British Isles (or part of that region) is covered with an air mass satisfying the provisos (a), (b), (c) and (d) already stated. Easily remembered approximate values of H_F are 0, 2,500 and 5,000 ft. corresponding respectively to the values 9,000. 9,200 and 9,400 ft. Having obtained H_F it is a matter of a moment's thought to get the height of the freezing level above mean sea level by noting the relevant forecast either of mean-sea-level pressure (prebaratic) or of the 700-mb. contour height (prontour).

That this method is in most cases sufficiently accurate in practice is seen from the fact that the standard deviation in H_F is equal to 460 ft., whilst forecasts normally contain the height of the freezing level only to the nearest 1,000 ft.

The case t_7 equal to or greater than 9,500 ft.—Relaxation of proviso (a) decreased the correlation considerably, as the "cold" air in this case was generally very degenerate and shallow with a stable lapse rate of temperature or even an inversion. The correlation method does not give the height of the freezing level with the same degree of accuracy and has not been worked out. However, Table II gives some figures as a guide, although the ranges given for H_F did not include every case.

TABLE II

t_7 H_F	<i>feet</i>	
	9,500 6,000-8,500	9,600 8,500-11,000

THE EFFECT OF WATER DROPLETS ON THE BUOYANCY OF A RISING CUMULUS CLOUD

By J. M. CRADDOCK, M.A.

•One familiar use of the printed tephigram (Form 2810A) is in the estimation of convective activity. In the usual "parcel" method, we consider a parcel of air which is saturated at the expected temperature at the condensation level, and assume that it rises by virtue of its buoyancy, cooling at the saturated adiabatic lapse rate until its temperature is once more equal to that of the environment. Our estimate of the cloud top is based on this new "equilibrium level", and of intensity of convection on the work done on the parcel during its ascent, as measured by the area on the tephigram between the environment curve and the saturated adiabatic which the parcel is assumed to follow. The sequence of events assumed is a simplified but fair representation of what actually takes place, and probably for this reason, the method has proved a most useful tool in the forecaster's hand. If the physical sequence can be followed more closely on the tephigram, the value of the method may be increased.

The saturated adiabatics on Form 2810A are computed on the assumptions, (a) that condensation takes the form of water droplets at temperatures above 32°F. and of ice at temperatures below 32°F., and (b) that the products of condensation are removed as they form. It is now accepted that, under convective

conditions, condensation is mainly in the form of water droplets even at temperatures much below 32°F . so that the temperature of a rising cloud parcel will follow closely the saturated adiabatics with regard to liquid water. These "water" adiabatics are shown on the official Form 2810A (overprinted) recently issued by the Meteorological Office, and are reproduced with interpolations as the full lines in Fig. 1. The ice adiabatics which appear on the Form 2810A in general use are shown for comparison by dotted lines. The difference is not negligible.

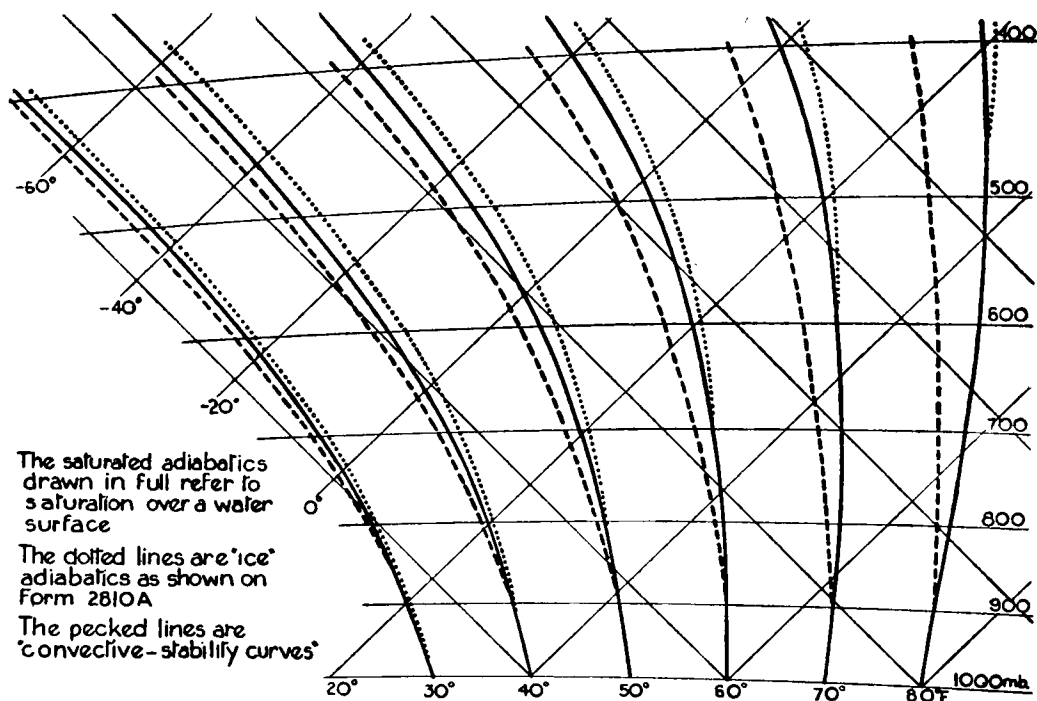


FIG. 1—"CONVECTIVE-STABILITY" CURVES ON A TEPHIGRAM

"Convective-stability curves" give the temperature of an environment having 100 per cent. relative humidity which is of the same effective density at all levels as a rising parcel of air which becomes saturated at 900 mb., and thereafter retains the liquid products of condensation

Furthermore, the growth of a convection cloud is a rapid process during which nearly all the products of condensation are retained within the cloud. For example, a cloud parcel 50 mb. deep which rises at 500 ft./min. for 10 min. will retain over 9 tenths of all droplets of radius 0.002 cm. and a higher proportion of the smaller ones. The heat energy of the retained droplets is thus available, in addition to the latent heat of condensing water vapour, to offset the work done in the expansion of the rising air, and the temperature of the rising cloud mass will fall rather more slowly than it would have done if the products of condensation had been lost. In the terminology used by Brunt^{1*}, the temperatures of the cloud mass will follow the reversible adiabatic rather than the pseudo-adiabatic. The difference is however small, being inappreciable at low temperatures and hardly exceeding 1°F . under extreme tropical conditions. In what follows the temperature of an ascending cloud parcel is assumed to be given by the "water" adiabatics in Fig. 1.

*See list of references on p. 354.

Although the effect of the water droplets on the temperature of a rising cloud parcel is inconsiderable, the effect on its density is important. A falling raindrop or cloud particle, which has reached its terminal velocity, exerts on the surrounding air a downward force equal to its own weight. This fact has been used, for example, by Buell² to compute the down-draught caused by heavy rain, and by H. Ertel³ to compute the liquid water content of a stationary cumulus cloud. A cloud charged with droplets is heavier (by the weight of the droplets) than a mass of air of the same temperature, pressure and humidity containing no droplets. Thus a droplet-charged cloud, to be in equilibrium, must be somewhat warmer than the environment, so that the residual buoyancy is just enough to support the weight of the suspended water. If the weight of suspended water is Δx gm./Kg., T the absolute temperature of the cloud and ΔT the excess of the temperature of the cloud over that of the environment, then for equilibrium

$$\frac{\Delta x}{1000} = \frac{\Delta T}{T} \quad \dots (1)$$

Now Δx can be estimated at any stage of the cloud development by the excess of the saturation humidity-mixing ratio at the condensation level over its value at the time considered, and equation (1) will give ΔT , the amount whereby the temperature of the environment must be below the appropriate "water" adiabatic if cloud and environment are to be in equilibrium. To illustrate this, "convective-stability curves" are shown in Fig. 1, which assume an initial condensation level of 900 mb., and at all higher levels fall short of the "water" adiabatics by the appropriate value of ΔT .

A rising cloud parcel, which condenses at the 900-mb. level, in a saturated environment represented by the "convective-stability curve" will be in equilibrium throughout its ascent, and will neither absorb nor generate kinetic energy. If the environment is not saturated, its density will be greater than if it was, and the cloud parcel will generate some kinetic energy. It is possible to allow for this by applying the virtual temperature correction to the convective-stability curve (assuming 100 per cent. saturation) and also to the environment curve, and this correction may in fact be necessary if the environment is intensely dry. In European conditions, however, where the environment is usually moist, the virtual temperature correction may be omitted, and the environment curve compared directly with the convective-stability curve. These will intersect near the true equilibrium level and the energy for maintaining the convective circulation is measured by the area between them. The area between the convective-stability curve and the saturated adiabatic represents work done in increasing the potential energy of the suspended water, and so is not available for maintaining convection.

The differences between the convective-stability curves and the saturated adiabatics are material, and it is suggested that the stability of an air mass should be judged by reference to the former. An environment curve lying between the saturated adiabatic and the convective-stability curve will be judged incapable of supporting convection, and in other cases the probable limit of convection will be below that which would have been estimated from the saturated adiabatics.

Experience shows that in temperate latitudes, shower-type precipitation is nearly always associated with the presence of ice crystals in the cloud top, so

that the forecaster who estimates the cloud top (based on the convective-stability curve) to be at temperatures above 32°F. will be disposed to dismiss the risk of showers. If, on the other hand, the rising cloud parcel is expected to penetrate the freezing level, the condensed water which weighs it down may be removed by precipitation. The effective buoyancy of the parcel will then increase and the cloud may rise to the limit estimated from the saturated adiabatic. It should be observed, however, that when the freezing level is penetrated rain formation need not start immediately, and that even when started the process takes time. It may be expected therefore that where the cloud top, estimated from the convective-stability curve, is not far above the freezing level, the rising cloud parcel will come to rest temporarily, until much of the suspended water has been shed.

These theoretical arguments were prompted by observation in the tropics, and serve to explain some characteristic features of tropical convection^{4,5}. At lower temperatures the effect of the weight of the retained water droplets on the buoyancy of a cloud is less, but still seems sufficient to require attention by the routine forecaster on the lines suggested.

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LUMINOUS NIGHT CLOUDS

By J. PATON, M.A., B.Sc.

A strikingly brilliant display of luminous night clouds was visible in Scotland during the night of July 10–11, 1949 after a weak though unmistakable occurrence on the previous night. The clouds appeared along the northern horizon in an otherwise empty sky about half an hour after sunset and soon stood out sharply defined against the darkening background. In shape and form they were identical with mixed cirrus fillosus and cirrostratus and could be distinguished from these normal clouds only by their luminosity. Their brilliant blue-white colour matched the twilight glow. Long parallel uniformly spaced cirrus-like streaks stood clearly defined in places against a dark background; sometimes curving to assume the shape of roughly coiled rope. In other parts the streaks were backed by a sheet resembling cirrostratus. The streaks showed only a slow change in form with time, each remaining easily identifiable on photographs taken after an interval of some twenty minutes or so. By contrast, the background showed continuous change, sometimes appearing as a perfectly uniform sheet, then suddenly developing within itself thin parallel waves, roughly perpendicular to the much brighter and more solid streaks (see photographs facing p. 356). This appeared to correspond precisely to the change from cirrostratus nebulosus to cirrocumulus undulatus. As midnight approached both the altitude and extent of the luminosity slightly diminished, then slowly increased again during the early hours of the morning. When first observed the clouds extended from 24° west to 56° east of north, the maximum

altitude being 11.5° . By midnight the altitude had fallen to nearly 10° and the western limit was now 18° west of north. The area of luminosity was thus at a minimum with the sun at its lowest point below the horizon. Thereafter, both the luminous area and brightness increased, the former progressing eastwards with the sun, and eventually fading in the brightening sky before dawn.

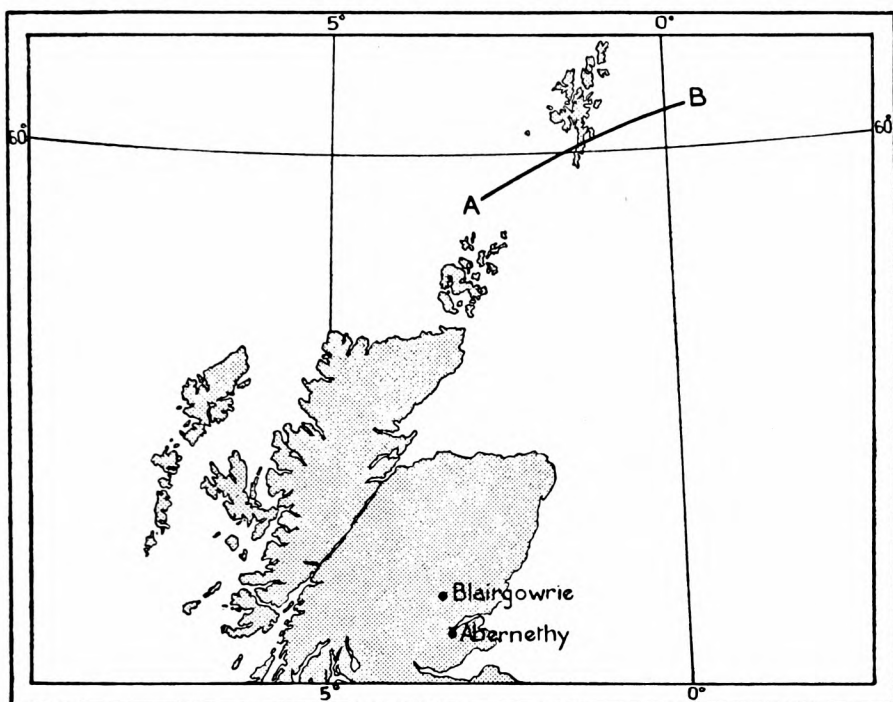


FIG. 1—MAP SHOWING THE ESTIMATED POSITIONS OF THE LUMINOUS NIGHT CLOUD ON THE NIGHT OF JULY 10–11, 1949

Pairs of simultaneous photographs by Størmer-Krogness auroral cameras were obtained at Abernethy and Blairgowrie, 27.6 Km. apart. Using Størmer's methods for measuring parallaxic photographs of aurora, this series will yield measurements of the height and position, the speed and direction of movement and the distance between successive crests of the clouds. Measurements of the two corresponding photographs used here as illustrations show that the upper "streak" marked AB on the photograph taken at Abernethy, extended roughly in a north-east to south-west direction over southern Shetland at a height of approximately 89 Km.

Mr. Schröder of Holmestrand secured excellent photographs of this display on daylight Kodachrome. Professor Størmer hopes to use them with a simultaneous position of the clouds, interpolated from our photographs to make measurements using the base line Holmestrand-Abernethy.

During the night of August 1–2, the Norwegian network secured 42 sets of simultaneous photographs from three stations, Oslo, Holmestrand and Askim, of a further display in the north and north-east. This was not visible in Scotland.

Although earlier observations of these rare clouds are probable, so striking is their appearance, the first recorded observations were made in 1885. From then until 1894 they occurred very frequently indeed and in most brilliant forms. Although so tenuous that stars shine through them without apparent reduction

in brilliance, on some occasions at this time luminosity was sufficiently great to cause shadows of terrestrial objects to be cast on the ground. Sometimes the clouds extended over the zenith to the south-east horizon. Omond observed them from Ben Nevis Observatory during the summers of 1887 and 1888 "on almost every clear night". The information collected during this period was analysed by Jesse^{1*}, who himself succeeded in measuring their height by photographic methods. He found that they were situated at heights of about 82 Km. and were observed only between late May and mid August and only in latitudes between 45° and 62° . They travel almost invariably with a westerly component, from north-east before and from east-north-east after midnight, with speeds often greater than 100 m./sec. On one occasion, Jesse recorded a speed of 300 m./sec. The distance between successive wave crests was found to be 9 Km. Their spectrum showed no emission lines but the Fraunhofer lines were easily seen. Jesse then concluded that they consisted of "foreign matter, perhaps the products of condensation of gases projected to great heights during volcanic eruptions", their luminosity being due to their reflection of light from the sun, 10° - 18° below the horizon.

Størmer^{2,3,4,5} employing his network of photographic auroral stations has confirmed Jesse's measurements of height, velocity and distance between wave crests and has suggested examination of their nature and height by radio and radar methods.

Vestine⁶ has made a statistical examination of observations between 1885 and 1923 and has shown that the distribution of nights of occurrence closely follows a normal error curve, the most likely time of occurrence being ten days after the summer solstice. It is then, too, that the clouds are most brilliant. He compares the yearly frequency of appearance of the clouds with yearly occurrences of volcanic eruptions, meteor showers and great comets and is led to the conclusion, to which Professor Størmer subscribes, that the evidence favours a cosmic rather than a volcanic origin for the constituents of the clouds. The remarkably frequent and brilliant displays of the period 1885-94, which had been usually ascribed to residual dust from the Krakatoa eruption of 1883, are deemed more likely to be associated with the equally remarkable number of meteor appearances, showers and great comets of the period 1880-87. That the great eruption of Katmai, Alaska, in 1912, was succeeded by no marked increase in frequency of these clouds, while the great Siberian meteor of 1908 was followed immediately by most brilliant displays is cited in support of this view. On the other hand, Vegard⁷ and others^{8,9} have suggested that the clouds may be composed of ice crystals.

Whatever uncertainty there may be concerning the nature and origin of the cloud particles, there can be no doubt that they are minute in size. The nature of their spectrum, revealing that their light is scattered sunlight, and their predominantly blue colour show that their diameter must be of the order of the wave-length of visible light. In the display of July 11, the lower edge of the clouds was tinged a reddish-brown colour soon changing to blue with increasing elevation, the maximum luminosity being at the maximum elevation. Observed through blue glass this increase in blue luminosity with elevation was even more clearly seen. On the other hand, when observed through red glass,

*These numbers refer to the list of references on p. 357.



Photos reproduced by the courtesy of J. F. McKellican
LUMINOUS NIGHT CLOUDS SEEN FROM BLAIRGOWRIE



Photos reproduced by the courtesy of J. Paton
LUMINOUS NIGHT CLOUDS SEEN FROM ABERNETHY
Parallactic photographs of luminous night clouds at 0019 G.M.T., July 11, 1949, from Abernethy and Blairgowrie 27.6 Km. apart. The star at the centre of the Blairgowrie picture and to the right of the centre of the Abernethy picture is Capella



IRIDESCENT CLOUD AT ALDERGROVE, 1545, NOVEMBER 24, 1948
(see p. 366)



Photo by the Royal Aircraft Establishment, Farnborough

ALTOCUMULUS CASTELLATUS AT FARNBOROUGH, 0840, JULY 13, 1945
The height of the base of the cloud is 8,000-10,000 ft.



Photo by R.A.F.

CUMULONIMBUS IN THE ENGLISH CHANNEL, 1909, AUGUST 27, 1945
 Taken from 20,000 ft. near the Channel Islands looking south-south-eastwards. A thundery trough is approaching from the south



Photo by R.A.F.

CUMULUS AND CUMULONIMBUS OVER BRITTANY, 1235, JULY 2, 1945
 Taken from 18,000 ft. looking north-north-east, showing cumulus development after the passage of a cold front



Photo by R.A.F.

RAPID CUMULUS DEVELOPMENT AT DISHFORTH
(see p. 368)

the clouds were just recognisable and red luminosity appeared to be uniform from the base to maximum elevation. The reddish-brown colour and diminishing luminosity towards the base of the clouds may be due to increasing selective atmospheric scattering in the increasing (with decreasing elevation) effective thickness of air during the passage from the cloud to observer. It may also result from depletion, mainly in the lower parts, of the illuminating solar beam during the passage of the light through the atmosphere before it reaches the clouds. Indeed, Størmer has shown that the luminosity decreases rapidly when the solar rays incident on the cloud traverse the atmosphere at heights lower than about 30 Km. from the earth's surface.

The main interest of these clouds to the meteorologist lies in the fact that, with meteor trains and perhaps certain residual forms of aurora, they provide the only direct means of ascertaining air movement at these high altitudes. Since they are situated near the earth's shadow, the information concerning air movement in this region may be especially interesting. But the most extraordinary feature of these luminous night clouds is their persistent appearance at the same height, between 80 and 90 Km.

Whether they are comprised of dust or ice, this constancy of height implies the existence of a minimum of temperature at the cloud level, for only then can, (a) the drift of dust to and its concentration in a layer at uniform height, or (b) the formation and persistence of a stratum of ice crystals, be explained. The latter requires that the temperature be of the order of 160°A . Evidence in support of the existence of such a temperature minimum comes from Whipple's¹⁰ examination of meteor-track photographs, which yields an estimate (apparently in good agreement with V-2 rocket results up to 70 Km.) of the gradient of density and so of temperature. This reveals a temperature maximum of the value 350°A . at 60 Km. and a minimum of 200°A . at 80 Km., a temperature-height distribution that accords with the occurrence of these clouds at 80–90 Km.

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OBSERVATIONS OF A THUNDERSTORM FROM SMALL CUMULONIMBUS

By F. H. LUDLAM

On October 4, 1948, a thunderstorm was reported from Bassingbourn and Duxford from unusually small thunderclouds whose tops were observed by several aircraft. Details in the following account of the storm have been supplied by the Meteorological Officers at the two stations.

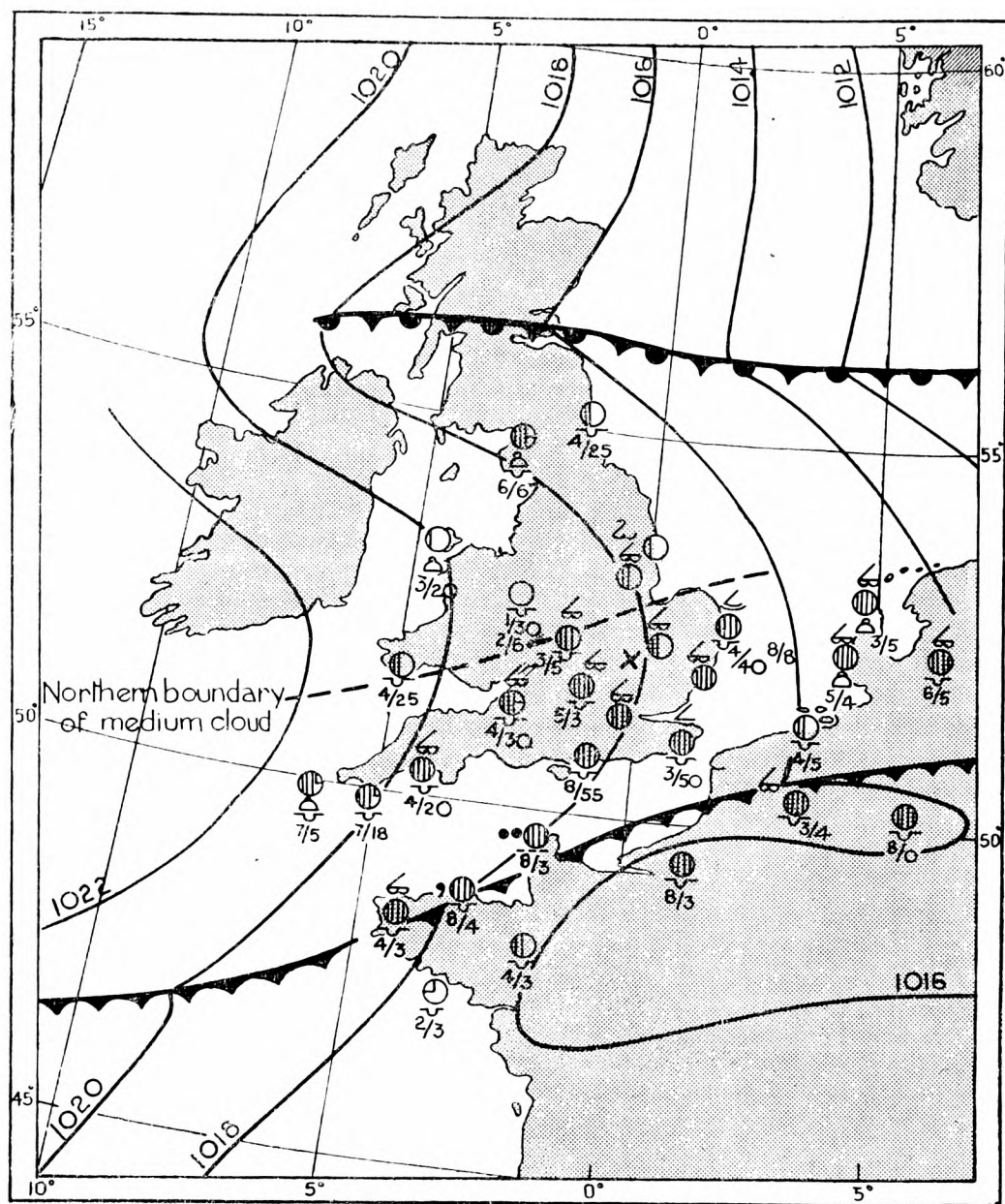


FIG. 1—SYNOPTIC CHART, OCTOBER 4, 1948, 0600

The position of Bassingbourn is marked by an **X**

In the early morning the British Isles were covered by a northerly air stream behind a cold front which at 0600 lay along the coast of north France (Fig. 1). A layer of medium cloud on the cold-front surface extended northward over the English Channel and the south of England, with its northern boundary lying roughly along a line from Pembroke to The Wash. The medium cloud was broken in many places and contained some castellatus; below it there was at first little or no low cloud, but by 0800 some cumulus and stratocumulus was reported. The edge of the system of medium cloud was moving south as the cold front receded, and by 0900 the upper cloud lay almost entirely south of a line from Hartland Point to Yarmouth. At this time Bovingdon reported a shower,

and Wittering a shower in the last hour. Both stations reported large amounts of low cloud, but Bassingbourn experienced a slight shower at 0820 from upper cloud and first observed large cumulus at 0850. Examination of the Downham Market 0800 radio-sonde sounding (Fig. 2) suggests that the cumulus which was forming about this time, probably helped locally by orographic ascent, might continue to grow to between 15,000 and 16,000 ft., where the temperature was about -18°C . Between 0900 and 1000 a group of showers approached the Duxford-Bassingbourn area, and at 1015 both stations reported a thunderstorm with moderate to heavy rain. Two brilliant lightning flashes were observed from Bassingbourn and at Duxford about six separate peals of thunder were heard. Meteor pilots who were in the area at the same time reported chaotic cloud up to medium levels with cumulus and cumulonimbus tops reaching up to between 12,000 and 15,000 ft. (one pilot saw a lightning flash near Bassingbourn). A Spitfire of the Aero Flight, R.A.E., was also in the neighbourhood, and Mr. Jones of the East Hill radar station (near Dunstable), who was controlling its investigation, has kindly made available records which make it quite clear that the aircraft flew through the same cloud mass. The pilot did not report any thundery activity, but confirmed that the cloud tops were at about 13,000 ft. The precipitation echoes observed by Mr. Jones reached a maximum height of about 12,000 ft.

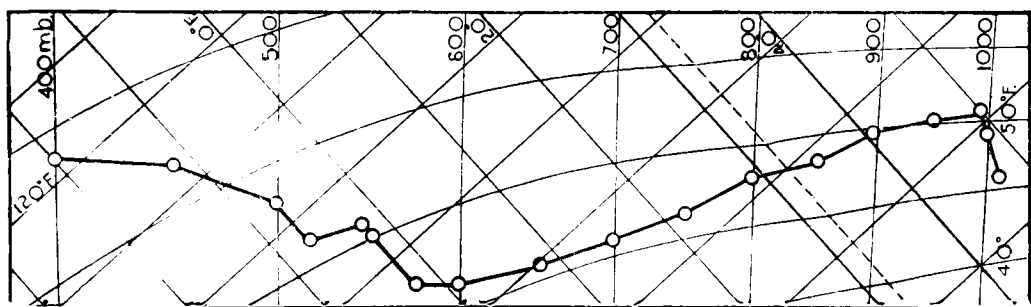


FIG. 2—RADIO-SONDE SOUNDING, DOWNHAM MARKET, OCTOBER 4, 1948, 0800

The deterioration did not last long; about 1030 the rain ceased at both Duxford and Bassingbourn, and Bassingbourn reported that at 1100 the storm cloud could be seen to the south-east, but that otherwise there were only small cumulus in the sky, with no trace of the medium cloud which had been extensive before the storm. The Meteorological Officer at Duxford remarked that the improvement was typical of that usually experienced after the passage of a moderately vigorous cold front. This must be regarded as fortuitous, however; an examination of the synoptic data does not reveal any secondary cold front, but does show that the system of medium cloud was still moving away southward and that the thunder shower had occurred near its northern limit. It is remarkable that farther south showers were later reported (from Croydon and Scilly) near the edge of the medium cloud system, but that farther north the cumulus over inland areas south of 53°N . became small as the air became drier and the cloud base rose. It seems possible that the medium cloud was producing a considerable ice-particle precipitation which mostly evaporated long before reaching the ground, but which served to effect a kind of natural "seeding" of the tops of some of the larger cumulus.

Nevertheless it is clearly evident that a slight thunderstorm was produced by cumulonimbus whose tops were below 15,000 ft. (temperature above $-20^{\circ}\text{C}.$), and it is believed that thunder from such a small cloud is very unusual. Elsewhere the writer has suggested that a temperature of about $-32^{\circ}\text{C}.$ in the cloud tops may be a threshold temperature separating thunderclouds from showerclouds. Further evidence for or against this view would be very welcome.

BASIS FOR EXTENDED FORECASTING AS PRACTISED IN THE UNITED STATES WEATHER BUREAU

By J. NAMIAS

A large and appreciative audience, both from within and outside the Meteorological Office, attended a lecture given at the Science Museum on September 26 by Mr. J. Namias, on the subject quoted in the title. This was the second of the special lectures by distinguished meteorologists visiting this country which we have had the privilege of hearing this autumn, the first by Dr. T. Bergeron having been reported in the November 1949 issue of the *Meteorological Magazine*.

The Director, introducing Mr. Namias, said that the audience would have been even larger were it not for the prior claims on forecasters' time of the R.A.F. exercise "Bulldog". The name of Mr. Namias was well known to all, first, as a leading exponent of the technique of isentropic analysis, and latterly as the Chief of the U.S.W.B. Extended Forecast Section. The fact that the extended forecasting experiment in this country had been the subject of one of our own discussions early this year would make Mr. Namias' lecture all the more interesting.

Mr. Namias, in a brief historical introduction, explained that research by the Weather Bureau and the Massachusetts Institute of Technology into the problem of extended forecasting was started by a resolution of Congress following the severe droughts in the United States in the early 1930's. After some five years of preliminary investigations the regular issue of forecasts covering five days was begun in 1940, the basic research meanwhile proceeding side by side with the operational work. There are two essential features of the United States technique of extended-range forecasting; the first, which will be generally agreed, is the necessity of considering the atmospheric circulation over at least the whole hemisphere; the second, which might not find such general acceptance, is the necessity for viewing broadly the time sequence of events, by working principally with mean charts for the five-day period. The mean-map technique smooths out the transitory features and gives true prominence to the semi-permanent centres of action, the significance of which all must recognise.

With the aid of a series of clear and purposeful slides, Mr. Namias then gave an account of the U.S.W.B. extended forecasting practice. The basic tool is the forecast five-day mean 700-mb. contour chart, which generally shows a circulation round the pole, on which are superimposed large-scale slow-moving ridges and troughs, more or less regularly spaced round the hemisphere (Rossby long waves). These troughs are the aggregates of the faster-moving daily troughs, and mark the positions at which the daily troughs reach their greatest development. Topographical features serve to "anchor" troughs or ridges in certain longitudes, and resonance induces a series of troughs and ridges downstream,

whose movement and spacing can be estimated from Rossby's well known formula. Strictly, the formula applies to actual troughs and ridges, but has been modified empirically to apply to mean charts. The forecast mean surface chart is constructed from the mean 700-mb. chart by adding the field of normal thickness, modified to allow for expected thickness anomalies.

These physical considerations are supplemented by kinematical methods based on extrapolations and trends, and the forecast mean charts are constructed so as best to take account of all these factors. The interpretation of the chart in terms of forecast weather is in part an objective process; the basic forecast gives expected five-day anomalies of temperature and precipitation which are arrived at from supplementary statistical material showing the distribution over the United States of the correlation between these anomalies and the anomalies of the 700-mb. pattern derived from the forecast chart. Experience has shown that this is a reliable method of forecasting general conditions over a period. Although daily forecast charts for the five-day period are prepared also, only small success has so far been achieved in forecasting in detail the weather for any place beyond two or three days; the U.S.W.B. has gone no farther than our own service in meeting, for example, the demand for advance forecasts for public holidays.

A considerable number of questions, mainly on points of detail in forecasting procedure, were put by members of the audience and answered by Mr. Namias. The Director then expressed the thanks of all present for a most enjoyable lecture, outstanding for its clarity and ease of presentation of a subject, which surely must have been most difficult to treat so adequately and yet to compress into the time available.

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METEOROLOGICAL OFFICE DISCUSSION

The first discussion of the 1949-50 series, held at the Imperial College on October 3, 1949, dealt with the results of the United States Thunderstorm Project, and was opened by Mr. F. E. Coles.

The U.S. Thunderstorm Project was organised by the National Advisory Committee of Aeronautics U.S. Weather Bureau, U.S. Navy and U.S. Air Force to investigate the structure of thunderstorms with the aim of evolving safer flying techniques. The Project was directed by Dr. H. R. Byers. It was carried out in two phases, the first to study the subtropical thunderstorms of Florida, and the second the frontal and air-mass thunderstorms in the higher latitude of Ohio.

The thunderstorms were observed by a dense network of ground stations, one to two miles apart with automatic recording instruments, and by radio-sonde and radar wind stations. Specially equipped P61 aircraft made simultaneous traverses through thunderstorms at altitudes between 5,000 and 26,000 ft., normally with 5,000-ft. height separation, and observed turbulence intensity, extent of cloud and hydrometeors. Ground radar stations guided the aircraft and studied the development and movement of the thunderclouds. Frequent photographs were taken of radar scopes and aircraft instruments and all observations were carefully synchronised.

Results indicated that thunderstorms usually consisted of several turbulent convective cells about 1–5 miles in diameter and in various stages of development, separated by relatively smooth corridors about a mile or less wide. Single-cell storms were rare, although each storm probably originated as such, but other cells soon formed once the first cell had produced rainy conditions. Radar and rainfall patterns confirmed a cellular structure.

There appeared to be three stages of development in each cell:—

In stage 1 there is convergence at all levels, and an up current prevails throughout the cell, possibly attaining a speed of 100 ft./sec. in well developed cells, consequently condensation and growth of water-drops occur.

In stage 2, which is the peak stage, water-drops fall to the surface and drag a certain amount of air with them, so causing a down draught to develop, while cooler, drier air is also frictionally entrained from the environment by the down draught, which is further cooled by evaporation of rain, and sinks towards the surface. Many striking features of the thunderstorm, such as the heavy rain, first gust squall line, fall of temperature and rise of pressure are apparently associated with the cold down draught air. On reaching the surface the cold air spreads out and soon outruns the rain area and sometimes appears up to 12 miles ahead of the original radar echo. This process often appears to trigger the formation of a new radar echo which forms behind the first gust line and may often merge into the parent thunderstorm. New thunderstorm cells usually form 3 miles or less down wind from an existing cell or between two cells less than 3 miles apart. In this stage, observations showed convergence at most levels of the cell, but divergence above about 25,000 ft. and below 5,000 ft. The surface divergence maximum was related to the maximum intensity of surface rainfall. The down draught does not extend much above 25,000 ft., probably because at higher levels there is insufficient water to produce significant precipitation.

In stage 3, termed the anvil or dissipating stage, the down draught spreads across the lower part of the cell until the up draught becomes of secondary importance. Eventually down draughts decreasing to about 20 ft./sec. or less occur throughout the lower levels of the cell, while above 25,000 ft. there are only small vertical motions. Rain becomes lighter and the thundercloud starts to dissipate first at the lower levels.

Upper wind and aircraft data confirmed the fact of entrainment of the environment by up and down draughts. Consequently the lapse rate in the up draught normally exceeded the saturated adiabatic, while the down draught was cooler than if it had gained heat at the saturated adiabatic rate.

The main flight hazards to aircraft in thunderstorms were turbulence, hail, lightning and icing. Pilots found that turbulence was least at 5,000–6,000 ft., and generally greatest between 15,000 and 20,000 ft., but there was little difference between the frequency of heavy turbulence at medium and high levels. It was important to distinguish between draughts and gusts. Draughts were the large scale up and down currents usually continuous over several thousand feet and lasting up to 30 min. with varying speeds. Gusts were smaller scale more transient phenomena similar to surface gusts. Normally draught velocities greatly exceeded gust velocities, but the larger gusts were invariably associated with strong draughts. Radar measurements suggest that up-draught velocities increased with height up to about 10,000 ft. below cloud top.

Hail was encountered by project aircraft mainly near the freezing level and least at the lowest and highest levels flown, and caused no major damage.

Lightning strikes on the aircraft occurred mainly at 16,000 and 26,000 ft. at temperatures from $+2^{\circ}\text{C}.$ to $-25^{\circ}\text{C}.$ but no major radio failure or serious damage occurred.

Wet snow packed on the leading edges of the aircraft on about a quarter of the traverses, and reached a thickness of about a quarter of an inch, but icing was never a serious hazard in the relatively short period aircraft were flying in thunderclouds.

Commenting on the investigation Mr. Coles said that although over 1,300 traverses of thunderstorms were made no details were given of the number of separate storms investigated. Further investigations below 5,000 ft. and above 26,000 ft. were desirable. This was particularly necessary above 26,000 ft. as it appeared that up draughts and associated turbulence might increase with altitude above 26,000 ft. Judging from the maximum altitudes of thunderstorm echoes measured by radar and the fact that actual cloud tops normally exceed these figures, it seemed likely that on some occasions the thunderclouds penetrated into the stratosphere.

The Director, opening the discussion, asked how convergence and the speed of draughts were calculated, whether the formation of secondary echoes behind the first gust line was due to mechanical lifting by the cold air and whether there was any strong evidence of tops of thunderclouds penetrating into the stratosphere.

Mr. R. G. Veryard referred to desert duststorms and thunderstorms, and thought that evaporation of rain into dry air was one of the main factors in the cold down draught. He asked whether the Americans had related wet-bulb temperatures to the level from which the air had come, and how various intensities of precipitation had been observed from aircraft.

Mr. J. L. Galloway emphasised that the investigation gave no information about conditions above 26,000 ft. The work had been done in strong P.61 aircraft but would similar results apply to the average heavy bomber?

W/Cdr. S. W. Hughes, Assistant Director of Training (All Weather), said that he had himself flown in a number of traverses made by aircraft of the Project and had later been closely concerned with the discussion of the observations. The P61 aircraft used were not specially strengthened, and the results can be applied to any aircraft and safe penetration speeds calculated. Some heavy aircraft did not appear suitable for thunderstorm flights in which a 43-ft./sec. maximum gust might be encountered. However, the All Weather Airline from Washington to Clinton had been flying in C54 aircraft through many thunderstorms in the past 2 years, but flew below 10,000 ft. during thunderstorms to avoid the worst turbulence.

Mr. R. F. Jones thought that the risk of icing had been underrated, as there had been two occasions when the R.A.E. Spitfire working with East Hill radar station (Bedfordshire) had been forced to abandon a thunderstorm traverse owing to severe icing, and one occasion when the V.H.F. aerial had been broken due to icing. Nor was he convinced that the regions between thunderstorm cells were quite as calm as suggested. Although the edges of the radar echo

columns appear to be the most turbulent, some quite large gusts had been recorded in the troughs between the columns. The definition of a thunderstorm based on radar-echo tops exceeding 25,000 ft. was rather arbitrary, and it seemed probable that this height was rather low and that a large proportion of the clouds flown through were not actually thunderstorms. The strongest gust experienced by the R.A.E. Spitfire was at 30,000 ft., and it appeared that turbulence increased upwards in a thundercloud, until a height of rather less than half the vertical extent of the cloud was reached, and then remained more or less constant until near the top of the cloud.

As regards down draughts, comparison of R.A.E. Spitfire flights with radar echoes suggests that the typical echo columns are associated with up draughts, and that down draughts are associated with a part of the cloud clear of echo. It may be that the greatest echo is associated with large raindrops which cannot fall to the ground because the up draught is too strong, but if heavy rain is associated with the down draught this should also give an echo. Possibly this discrepancy arises from the assumption that water accumulates in the up draught until it could no longer be supported, but this overlooked the limiting size to which a raindrop could grow. Further growth beyond about a quarter of an inch diameter would result in disruption, and the smaller drops so formed would be carried more quickly upwards. If the upward current now spreads out near the cloud top, the vertical component of the current decreases and the small drops would then fall down outside the vicinity of the strongest current and probably in a down draught. Such small drops would not give a radar echo, nor the heavy thunderstorm rain, which Mr. Jones felt was associated with the up draught, but strong echoes would be obtained from the large drops travelling upwards in the up draught or possibly slowly down in the weaker parts of the current. He wished to know if there were any alternative ideas as to the cause of the down draught.

Mr. C. K. M. Douglas said that the observed frequency of hail was less than might be expected. In the high Alps heavy hail or soft hail was usually, if not always, present at the phase of maximum activity when a large cumulus head first became glaciated. Melting of hail would reduce the wet-bulb potential temperature of a descending air mass, but this would not be done by mixing if the wet-bulb potential temperature decreased upwards as it should do in a thunderstorm area. For students of clouds the position would be clarified if the presence of a number of cells within a unit cumulonimbus cloud were distinguished from cells which correspond with such clouds. A diameter of 1-5 miles had been mentioned, but 1 mile was small in relation to that of a normal well developed large cumulus. Large cumulus in lines or groups often reached an advanced stage of development before any one of them produced a shower.

Mr. J. S. Sawyer said that the use of radar in the Project directed attention to the life history of the radar echo rather than that of a true circulation cell. If the up currents were inclined, the large water-drops which caused the echo might fall out into a fresh mass of air which would be cooled and descend. The change from upward to downward motion in the radar echo did not necessarily imply a reversal of the circulation. Mr. Sawyer also said that it was difficult to believe that entrainment of air could have a major effect on the lapse rates, because it would require the intimate mixing of two masses of air a mile or more in diameter in a period of about ten minutes—was turbulence great enough for this?

Mr. J. M. Craddock said that large convective clouds generally consisted of a group of towers rising close together and might be expected to show a cellular structure. He thought the weight of the suspended water which produced the down draught was also important during the early stages of convection and referred to work published on p. 351 of this issue of the *Meteorological Magazine*. Convection of the intensity described was a very effective means of transferring energy upwards, while the supplies of energy obtainable from air-mass instability or from current insolation were comparatively small. Hence the mean fraction of any large area occupied at any instant by active convective cloud must be very small.

W/Cdr. Hughes said it was not true to say that aircraft should always be slowed down, as in some cases the best penetration speed was above the cruising speed. He did not think there were many people who had qualms about down draughts at low levels, but considered that hail was one of the greatest hazards. He hoped that the R.A.F. might investigate thunderstorms in the Far East, possibly in collaboration with the United States Air Force.

Mr. A. W. Brewer pointed out that many of these ideas were quite old. Many years ago, Normand showed that a down draught is necessary for the release of the full amount of energy of a thunderstorm while the entrainment of air by jets was well known to aerodynamicists, and was considered in detail in the wartime FIDO work.

Mr. Coles stated in reply that most of the convergence figures were calculated by a graphical method due to Bellamy. Draught velocities were normally estimated from aircraft height changes in a given interval on occasions when no appreciable movement of aircraft controls occurred. The cause of secondary radar echoes behind the first gust line might well be a trigger action started by lifting at the miniature cold front. There seemed to be a strong probability that on some occasions thundercloud tops penetrated the stratosphere. In reply to Mr. Veryard the levels from which down draughts originated had not in the papers considered been related to wet-bulb temperatures. In reply to Mr. Sawyer it was probable that large horizontal gradients of temperature existed in the draughts and complete mixing only occurred near the edges.

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ERRATUM

Page 318, Fig. 2 caption, line 4; for "The continuous lines are isonormals" read "The continuous lines are isanomalies."

METEOROLOGICAL RESEARCH COMMITTEE

The 58th meeting of the committee was held on October 12. The committee was primarily concerned with the general direction of the research effort of the Meteorological Office but there was some detailed discussion of difficulties encountered in the investigation of the high atmosphere by the use of a high-power pulsed light searchlight.

The 6th meeting of the Instruments Sub-Committee of the Meteorological Research Committee took place on October 27. The use of "window" in conjunction with radar for the measurement of winds at high altitudes was discussed and it was agreed that the method is practicable.

There was also some discussion of the means of avoiding radiation errors in radio-sondes. There is some evidence that such errors can be reduced to insignificant values by the use of temperature elements in the form of very fine wires. This matter is being pursued.

Two other matters connected with radio-sonde instruments—methods of comparison of height measurements by radio-sonde and radar* and the errors of radar wind observations on weather ships—were also considered.

LETTERS TO THE EDITOR

Multiple tropopauses

In Dr. Scrase's interesting article in the October issue of the *Meteorological Magazine* reference is made to "a multiple tropopause of the type first suggested by Bjerknes and Palmén" in 1937. I had almost forgotten that I myself pointed out much earlier, viz. in 1922, that this phenomenon sometimes occurred in our latitudes. Using the data of the balloons-sondes of Paris and Uccle of October 5, 1911, and the pilot-balloon ascents of Copenhagen and Uccle, I showed that over Belgium on that date the polar tropopause was at about 8.6 Km., the change from polar stratosphere to tropical troposphere at about 11 Km. and the tropical tropopause at about 15 Km. A note on the subject was published in the *Quarterly Journal of the Royal Meteorological Society, London*, **49**, 1923, p. 16.

Also Ramanathan pointed out in 1929 that multiple tropopauses occur over northern India between the months of November and April. The major references to his work are *Mon. Weath. Rev., Washington, D.C.*, **57**, 1929, p. 64, *India met. Mem., Poona*, **25**, 1930, p. 163, and *Nature, London*, **132**, 1933, p. 932. Over Agra the lower transition occurs at 12–13 gdKm. and the second at about 17 gdKm. In the *Nature* article he showed also, with references to published upper air data, that multiple tropopauses occur over the United States in summer.

A. H. R. GOLDIE

October 14, 1949

Remarkable cloud spectacle seen at Aldergrove

On the afternoon of November 24, 1948, a most beautiful cloud spectacle was observed at Aldergrove. There were two rather small patches of altocumulus, lenticular in form and in a slowly dispersing condition, situated 20–25° above the horizon to the south-west of the station. This cloud, while it was definitely altocumulus, was doubtless rather high for medium cloud, being estimated at about 20,000 ft. The observer has no doubt, however, that

* HARRISON, D. N.; *Met. Res. Pap., London*, No. 504, 1949.

it was not at any phenomenal height, for there was ordinary cirrus about at the time, this latter being definitely above the level of the cloud in question. Along the south-western quadrant of the horizon was a bank of strato-cumulus, base near 2,000 ft., top 3,000–4,000 ft., the edge of which formed a line 5–10° above the horizon. Behind this layer, in the south-western sky, by 1530 G.M.T., the sun, red with the rather thick haze, had set, but of course was still shining on the medium-cloud patches. At this time there appeared in these lenticular patches a remarkable iridescence, the colours ranging from a deep violet running in a band around the whole edge of each cloud, followed by similarly shaped bands of green, yellow (rather fainter) then red. The successive boundaries of each colour clearly followed the exact pattern of the outline shape of the cloud. Within the last fringe, the red, was a patch of brilliant green, occupying the interior portions of the cloud. It was remarkable to see that, while there was some tendency for the successive colours from the violet inwards to the red to merge a little from one to the next, there appeared no such boundary conditions between the red and the interior green patches, the change between these being quite abrupt. It has just been remarked that there was some sign of gradual transition from one colour to another from the outer edge of the cloud into the red fringe, but the transition was really far more abrupt than it is between the successive colours of the ordinary rainbow; moreover while close examination showed that all the spectrum colours were present, it was only the violet, green and red which appeared clearly distinctive, and very brilliant.

H. W. HILL.

A photograph of the cloud referred to above was taken at R.A.F.N.I. Headquarters at 1545, about 15 minutes after the iridescent cloud was first observed at the Aldergrove Office a mile away (see centre of this Magazine).

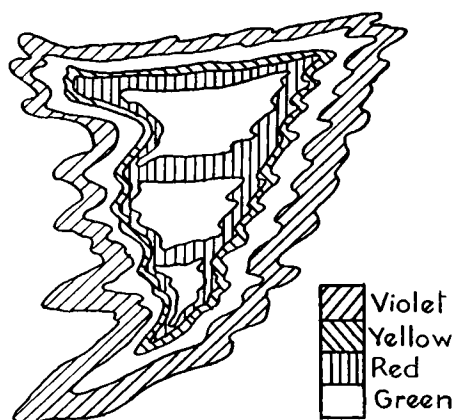


FIG. 1

At this time the predominating colours were green and pinkish red and both were vivid. These two colours were positioned in such a way that the protuberances in the cloud were pinkish red and the hollows vivid green and gave a remarkable patchlike colour effect of great beauty.

The three main patches of green drawn in the sketch supplied by Mr. Hill (Fig. 1), compare very well with the three main dark patches or hollows in one of the two iridescent clouds shown in the accompanying photograph taken some

fifteen minutes later. Fading of the colours became fairly rapid and only a faint indistinct green interspersed with patches of reddish brown remained after ten minutes (from 1545).

An interesting feature brought out by the photograph is the faint nebulous background of higher cloud behind the iridescent cloud. This higher cloud was not visible to the eye and is not to be confused with the very small amounts of cirrus present in the sky but not in the photograph. Apart from the low bank of stratocumulus, the background to the iridescent cloud appeared to be blue sky during the shorter period of the observations when the photograph was taken. A deep red filter was used. Small horizontal ripples in the cloud structure were plainly visible when the colours had almost disappeared.

A. WALTERS.

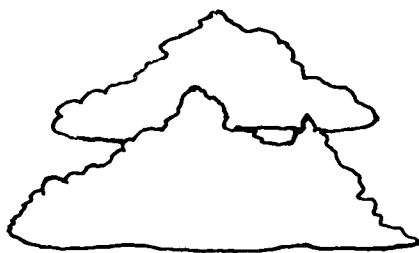
[On November 24, 1948, the height of the freezing level over Aldergrove was about 11,000 ft. and the temperature at 20,000 ft. was about -9°F .—Ed. *M.M.*]

NOTES AND NEWS

Rapid cumulus development at Dishforth

Mr. P. S. Griffiths of Dishforth has recorded the following notes on the rapid cumulus development at Dishforth on June 28, 1949. At 1400 G.M.T. an anti-cyclone was situated to the west of the Hebrides with a slack north-easterly gradient over north-east England and a weak occlusion, from west of Norway to the Scottish border, was moving slowly south-east. The airstream ahead was moist and rather unstable between 7,000 and 14,000 ft.

Small cumulus at midday, was observed to be developing rapidly over the whole sky by 1400 when the photograph facing p. 357 was taken. The surface temperature by this time had risen to 83°F . The cumulus on the right of the photograph was first observed as a small bubble above the layer



AA whence it developed into that shown in a matter of 20 minutes. Theodolite observations on the ascent of peaks of cloud in three successive minutes showed an ascent of 1° in the first minute, 0.5° in the second and 0.8° in the third. Unfortunately it was not possible to locate exactly the position of the particular cloud but it was estimated at some 12 miles to the north. (This would indicate an ascent of 1,000 ft./min.). This development was not restricted to this particular cloud but similar convection was going on over the whole sky.

Previously the rather unusual occurrence of cumulus cloud developing from two distinct levels had been observed. There was no doubt about this because the tops of the lower cloud were observed rising in front of the base of the higher development as shown in the accompanying sketch. The bases were estimated at 2,500 and 4,500 ft.

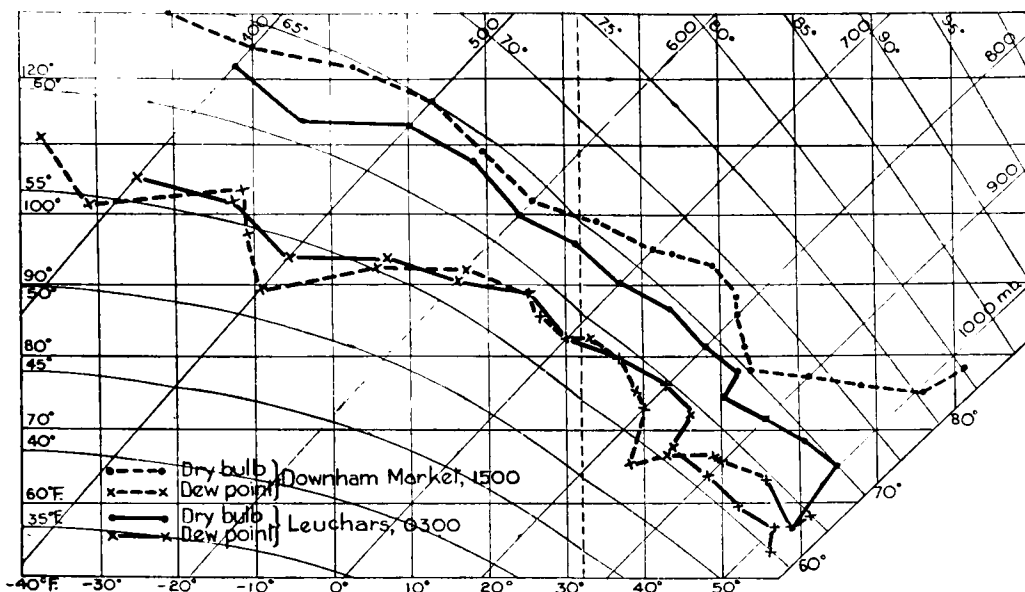


FIG. 1—TEPHIGRAM OF UPPER AIR ASCENTS OVER DOWNHAM MARKET AND LEUCHARS, JUNE 28, 1949

The ascent at Leuchars was made just ahead of the occlusion

[I should call the cloud on the right cumulonimbus which is also visible in the background. A rate of growth of 1,000 ft./min. is large for this country but I should hesitate to call it exceptional. Though simultaneous growth of convectional clouds at different levels is not very rare, I have never seen anything quite like the sketch. The upper layer has generally the character of turret clouds, though the base is not necessarily at medium levels.—C. K. M. Douglas.]

THE WEATHER OF OCTOBER 1949

Mean pressure was above 1020 mb. in the Ukraine and over most of central and southern Europe, except the southern parts of Greece and Italy, and was also above 1020 mb. in Madeira. It was slightly below 1000 mb. south-westward of Iceland. The mean was a few millibars above normal in the region with pressure above 1020 mb. and also over the Mediterranean.

Over the British Isles the weather of October was abnormally warm until the 15th, subsequently very unsettled cooler conditions set in and lasted until the 26th. From the 25th or 26th onwards it was really cold, the weather seeming to change abruptly from summer to winter. The month was excessively wet over a large area including the Thames Valley and southward to the coast and locally in west Scotland. In north-east Scotland and much of north-east England it was drier than usual.

At the beginning of the month an anticyclone initially situated north of the Azores, moved eastward to central Europe. Meanwhile a depression south of Greenland and associated troughs moved east. Fair weather prevailed over the British Isles apart from slight rain in the west and north and considerable mist and fog. Very high temperatures were recorded for the time of year, the highest readings being registered for the most part from the 3rd to 5th. Maxima of 79°F. and 76°F. respectively were recorded at Camden Square on the 3rd and Manchester on the 4th, these readings being records at these places for October since the extremely high readings recorded in October 1921.

On the 6th and 7th a depression centred well out over the Atlantic westward of Ireland moved very slowly east-north-east, while secondary troughs moving east caused rain in the west and north. From the 8th to 10th a shallow trough of low pressure off our south-west coasts moved slowly north-east over the British Isles and was associated with a thundery type of rain which was fairly heavy locally. On the 11th a new deep depression was centred in mid Atlantic; this disturbance moved slowly north-east during the ensuing days reaching the north of Norway by the 14th. On the 11th troughs associated with this depression moved east over the British Isles giving rain generally and thunder locally, but thereafter a ridge extending from an anticyclone over south-west Russia moved north over England, and fair, very warm weather with morning fog prevailed, apart from local rain in Ireland and north-west Scotland.

Subsequently very unsettled and cooler weather set in, with frequent rain and thunderstorms and local gales. On the 17th a small depression moved rapidly across the Atlantic to north-west Ireland, deepening as it moved, and then turned north-north-east to the northern North Sea. Widespread gales occurred in the British Isles on the 18th, while rainfall was general and heavy in places from the 17th to 19th (2.74 in. at Keswick and 2.13 in. at Stronachlacher, Stirling, on the 17th). During the next few days an unstable maritime polar air-stream covered the country causing thunderstorms and heavy showers locally (3.41 in. fell at Balcombe Water Works, Sussex, and 2.73 in. at Patcham Farm on the 20th). On the 23rd a small depression off our south-west coasts moved rapidly across England to the North Sea and thence to the Baltic and on the 25th and 26th another deep depression crossed England to southern Scandinavia. Gales occurred on the 23rd, 25th and 26th, the one on the 23rd causing considerable damage and one death on the south-east coast of England. Rainfall was very heavy during this period, particularly on the 25th when falls of more than 2 in. were widely registered; 2.10 in. was measured at Ashford, Kent, and 2.61 in. at Howick Hall Gardens, Northumberland, on the 23rd, 3.00 in. at Mindrum, Northumberland, 3.15 in. at Donaghadee, Co. Down, 3.50 in. at Peebles, Midcalder, and Mid Lothian and 3.60 in. at Largs, Ayrshire, on the 25th and 2.13 in. at Knockholt, Kent, on the 26th. On the 27th the Azores anticyclone with a ridge extending northwards moved east over the British Isles and thereafter to Germany and maintained fair weather, apart from fog in south-eastern districts, but troughs of low pressure associated with Atlantic depressions caused rain at times in the west and north.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days difference from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	79	22	+3.5	155	—1	103	32
Scotland ..	72	17	+3.1	131	+1	81	22
Northern Ireland ..	69	31	+3.2	139	+3	85	23

RAINFALL OF OCTOBER 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	4·83	184	<i>Glam.</i>	Cardiff, Penylan ..	8·72	184
<i>Kent</i>	Folkestone, Cherry Gdns.	7·75	192	<i>Pemb.</i>	St. Ann's Head ..	7·17	163
"	Edenbridge, Falconhurst	8·49	236	<i>Card.</i>	Aberystwyth ..	8·67	209
<i>Sussex</i>	Compton, Compton Ho.	9·67	211	<i>Radnor</i>	Tyrmynydd ..	8·09	122
"	Worthing, Beach Ho. Pk.	7·57	209	<i>Mont.</i>	Lake Vyrnwy ..	9·33	155
<i>Hants.</i>	Ventnor, Roy. Nat. Hos.	8·06	205	<i>Mer.</i>	Blaenau Festiniog ..	12·48	122
"	Bournemouth ..	7·61	179	<i>Carn.</i>	Llandudno ..	4·61	137
"	Sherborne St. John ..	7·32	208	<i>Angl.</i>	Llanerchymedd ..	7·21	161
<i>Herts.</i>	Royston, Therfield Rec.	4·53	167	<i>I. Man.</i>	Douglas, Borough Cem.	6·29	139
<i>Bucks.</i>	Slough, Upton ..	6·16	220	<i>Wigtown</i>	Port William, Monreith	5·26	133
<i>Oxford</i>	Oxford, Radcliffe ..	6·38	221	<i>Dumf.</i>	Dumfries, Crichton R.I.	6·39	162
<i>N'hant</i>	Wellingboro', Swanspool	4·32	171		Eskdalemuir Obsy. ..	7·51	139
<i>Essex</i>	Shoeburyness ..	5·29	224	<i>Roxb.</i>	Kelso, Floors ..	4·65	160
<i>Suffolk</i>	Campsea Ashe, High Ho.	3·40	130	<i>Peebles.</i>	Stobo Castle ..	5·38	156
"	Lowestoft Sec. School ..	2·56	92	<i>Berwick</i>	Marchmont House ..	5·63	147
"	Bury St. Ed., Westley H.	4·39	162	<i>E. Loth.</i>	North Berwick Res. ..	5·16	174
<i>Norfolk</i>	Sandringham Ho. Gdns.	3·93	129	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	4·25	155
<i>Wilts.</i>	Bishops Cannings ..	6·75	203	<i>Lanark</i>	Hamilton W. W., T'nhill	4·29	132
<i>Dorset</i>	Creech Grange ..	7·07	139	<i>Ayr</i>	Colmonell, Knockdolian	5·65	127
"	Beaminster, East St. ..	7·57	170	"	Glen Afton, Ayr San. ..	7·46	146
<i>Devon</i>	Teignmouth, Den Gdns.	6·51	168	<i>Bute</i>	Rothsay, Ardenraig ..	9·10	206
"	Cullompton ..	5·98	145	<i>Argyll</i>	L. Sunart, Glenborrodale	10·33	157
"	Barnstaple, N. Dev. Ath.	7·57	166	"	Poltalloch ..	6·45	131
"	Okehampton, Uplands	10·41	173	"	Inveraray Castle ..	8·97	127
<i>Cornwall</i>	Bude School House ..	8·17	201	"	Islay, Eallabus ..	5·49	115
"	Penzance, Morrab Gdns.	8·84	190	"	Tiree ..	7·47	164
"	St. Austell ..	9·22	175	<i>Kinross</i>	Loch Leven Sluice ..	4·67	136
"	Scilly, Tresco Abbey ..	6·21	163	<i>Fife</i>	Leuchars Airfield ..	3·72	143
<i>Glos.</i>	Cirencester ..	6·56	198	<i>Perth</i>	Loch Dhu ..	12·35	173
<i>Salop</i>	Church Stretton ..	4·41	120	"	Crieff, Strathearn Hyd.	6·31	161
"	Cheswardine Hall ..	3·92	126	"	Pitlochry, Fincastle ..	3·58	110
<i>Staffs.</i>	Malvern, Free Library	5·53	186	<i>Angus</i>	Montrose, Sunnyside ..	3·67	133
<i>Worcs.</i>	Birmingham, Edgbaston	5·42	195	<i>Aberd.</i>	Braemar ..	3·23	86
<i>Warwick</i>	Thornton Reservoir ..	5·36	196	"	Dyce, Craibstone ..	3·09	92
<i>Leics.</i>	Boston, Skirbeck ..	4·46	163	"	Fyvie Castle ..	2·42	63
<i>Lincs.</i>	Skegness, Marine Gdns.	2·87	105	<i>Moray</i>	Gordon Castle ..	1·75	55
"	Mansfield, Carr Bank ..	3·51	115	<i>Nairn</i>	Nairn, Achareidh ..	1·81	79
<i>Notts.</i>	Buxton Terrace Slopes	4·67	95	<i>Inv's</i>	Loch Ness, Foyers ..	2·77	82
<i>Ches.</i>	Bidston Observatory ..	3·32	102	"	Glenquoich ..	11·82	118
<i>Lancs.</i>	Manchester, Whit. Park	2·89	88	"	Fort William, Teviot ..	12·15	171
"	Stonyhurst College ..	4·64	103	"	Skye, Duntuilim ..	8·33	153
"	Blackpool ..	5·69	153	<i>R. & C.</i>	Tain, Tarlogie House ..	1·17	43
<i>Yorks.</i>	Wakefield, Clarence Pk.	3·02	105	"	Ullapool ..	2·32	49
"	Hull, Pearson Park ..	2·18	73	"	Applecross Gardens ..	8·21	138
"	Felixkirk, Mt. St. John	2·39	83	"	Achnashellach ..	8·18	108
"	York Museum ..	2·24	83	"	Stornoway Airfield ..	4·87	99
"	Scarborough ..	2·64	84	<i>Suth.</i>	Loch More, Achfary ..	7·90	101
"	Middlesbrough ..	2·40	80	<i>Caith.</i>	Wick Airfield ..	1·15	39
"	Baldersdale, Hury Res.	5·06	127	<i>Shet.</i>	Lerwick Observatory ..	4·45	112
<i>Nor'ld</i>	Newcastle, Leazes Pk.	2·18	71	<i>Ferm.</i>	Crom Castle ..	5·19	160
"	Bellingham, High Green	5·04	129	<i>Armagh</i>	Armagh Observatory ..	5·08	187
"	Lilburn, Tower Gdns. ..	5·77	156	<i>Down</i>	Seaford ..	5·97	168
<i>Cumb.</i>	Geltsdale ..	5·18	139	<i>Antrim</i>	Aldergrove Airfield ..	4·99	166
"	Keswick, High Hill ..	8·87	158	"	Ballymena, Harryville	5·36	145
"	Ravenglass, The Grove	5·14	119	<i>Lon.</i>	Garvagh, Moneydig ..	5·64	160
<i>Mon.</i>	Abergavenny, Larchfield	8·71	208	"	Londonderry, Creggan	5·84	159
<i>Glam.</i>	Ystalyfera, Wern House	10·01	145	<i>Tyrone</i>	Omagh, Edenfel ..	4·62	126

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, JUNE 1949

STATIONS	PRESSURE			TEMPERATURES								REL- ATIVE HUM- IDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
	Mean of day M.S.L.	Diff. from normal	Diff. from normal	Absolute		Mean values								Total	Diff. from normal	Days	Daily mean	Per- centage of possible																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
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